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ON THE SPECTROSCOPIC BINARY α^1 GEMINORUM.

By A. BÉLOPOLSKY.

My first photographs of the spectrum of this star (mag. 3.4, or, according to O.Σ, 3.7) were obtained for April 7 and 11, 1894, with the two-prism spectrograph of the Pulkowa Observatory mounted on the 30-inch equatorial. The two velocities in the line of sight, which I derived from the measurements by Vogel's first method (the star belongs to the same class as Sirius), differed by an amount which greatly exceeded the probable error of observation.

As I then suspected that the stars α^1 and α^2 Geminorum had been observed on the two nights, and not α^1 alone, but had no opportunity at that time to repeat the observations, the question whether the different velocities were real or not had to remain undecided.

It was not until January of the present year that I was able to resume the investigation, and I then found that my conjecture that the star is a binary was confirmed by thirty-two spectrograms, obtained between January 1 and April 26. In this connection I may remark that the spectra of α^1 and α^2 Geminorum are so different that one cannot possibly be mistaken for the other.

The exposure to the star was one hour; in the middle of the exposure the comparison spectrum of hydrogen was photo-

graphed. The star spectrum contains, besides the very broad hydrogen lines, all the stronger lines of iron, a circumstance which increases the certainty of the measurements. Using all the available material in the most careful manner possible[1] I obtained a series of values for the velocity of the star in the line of sight, and these values, after reduction to the Sun, exhibited a periodical change having a period of about 2.9 or 3.0 days. A closer approximation to the period was obtained by a consideration of the times at which the observed velocities in the line of sight were nearly zero. Such times are:

		Pulkowa Mean Time	Velocity
1896.	February	$24^d.418$	$+1^{km}.3$
	"	27 .367	−0 .9
	March	8 .363	+0 .9
	"	11 .321	+2 .7
	"	30 .350	+1 .7

Here it is necessary to take into account the fact that on February 24 and 27 and March 30 the velocities are increasing (changing from negative to positive values), and on March 8 and 11 decreasing. A short computation then gives for the actual times of zero velocity the following:

1896.	February	$24^d.399$ Pulkowa M. T.
	"	27 .379
	March	8 .375
	"	11 .358
	"	30 .326

Comparing those times which are separated by the shortest intervals (February 24 and 27, March 8 and 11) we obtain a period of 2.98 days; on the other hand, the period obtained from the dates February 24 and March 30, February 27 and March 30, is 2.91 days. I have used the latter value in computing the times of zero velocity, which are:

$$1896, \text{ February, } 27^d.34 \pm 2^d.91\, n,$$

where n is a whole number.

A provisional curve of velocities showed that the times of periastron passage occur $1^d.47$ later than the times of zero velocity.

[1] *Bull. Acad. St. Pétersburg*, December 1896.

In the following table are given, for each spectrogram obtained, the time at the middle of the exposure, the time of the nearest preceding periastron passage, the interval between this time and that of the observation, and finally the velocity reduced to the Sun.

LIST OF SPECTROGRAMS OF α^1 GEMINORUM.

Number	Date of Obs., 1896. Pulkowa M. T.	Periastron Passage, Pulkowa M. T.	Interval	Velocity relative to Sun
1	Jan. 1^d.43	Dec. 29^d.70	2^d.73	−26^{km}.8
2	20 .45	Jan. 19 .07	1 .38	+20 .6
3	Feb. 7 .43	Feb. 5 .53	1 .90	+22 .3
4	15 .45	14 .26	1 .19	+ 5 .6
5	19 .44	17 .17	2 .27	+18 .6
6	22 .42	20 .08	2 .34	+ 6 .2
7	23 .42	22 .99	0 .43	−33 .7
8	24 .42	22 .99	1 .43	+ 1 .3
9	25 .33	22 .99	2 .34	+16 .0
10	26 .36	25 .90	0 .46	−45 .4
11	27 .37	25 .90	1 .47	− 0 .9
12	Mar. 8 .36	Mar. 5 .63	2 .73	+ 0 .9
13	9 .32	8 .54	0 .78	−37 .9
14	11 .32	8 .54	2 .78	+ 2 .7
15	14 .38	14 .36	0 .02	− 9 .5
16	16 .33	14 .36	1 .97	+26 .1
17	17 .35	17 .27	0 .08	−38 .1
18	24 .38	23 .09	1 .29	−25 .7
19	30 .35	28 .91	1 .44	+ 1 .7
20	31 .36	28 .91	2 .45	+28 .5
21	Apr. 1 .36	31 .82	0 .54	−45 .0
22	3 .36	31 .82	2 .54	+22 .6
23	7 .36	Apr. 6 .64	0 .72	−40 .1
24	8 .36	6 .64	1 .72	+ 8 .6
25	11 .34	9 .55	1 .79	+ 7 .3
26	14 .35	12 .46	1 .89	+15 .9
27	17 .45	15 .37	2 .08	+17 .5
28	19 .39	18 .28	1 .11	−31 .3
29	20 .39	18 .28	2 .11	+20 .3
30	22 .41	21 .19	1 .22	−16 .5
31	24 .45	24 .10	0 .35	−47 .6
32	26 .40	24 .10	2 .30	+34 .7

With these values I constructed the curve of velocity, by taking the figures in the fourth column for abscissæ and those in the last column for ordinates. The scale was chosen so that 2 units = 1 geographical mile[1] (= 7.42 kilometers), 10 units

[1] In accordance with the practice of this JOURNAL (**3**, 1–3, 1896) the German geographical miles used by Herr Bélopolsky have been changed to kilometers, except

= 1 day. It is at once apparent that the curve can be drawn either through the points No. 7, 1, 2, 4, 3, 5, 6, 9, or through all the remaining twenty-four points. A single curve cannot be drawn at once which will satisfy all the observations. Leaving the eight points out of consideration, and drawing through the others a curve which fulfils certain known conditions,[2] we obtain the following results:

Motion of the system relative to Sun $= -1^{g.m}.06 = -7^{km}.9$

Area bounded by curve, maximum ordinate and axis of abscissæ; $z_1 = +1010$ units (diminishing velocity), and $z_2 = -1575$ units (increasing velocities) $z_1 - z_2 = 2585 \pm 7$.

Greatest positive ordinate, $A = 10.46 = 5^{g.m}.23 = 38^{km}.8$.

Greatest negative ordinate, $B = 10.94 = 5^{g.m}.47 = 40^{km}.6$.

Let u_1, u_2 = the longitudes of those points on the orbit for which the velocity in the line of sight = 0,

ω = longitude of the periastron,

e = eccentricity,

$\left(\frac{dz}{dt}\right)$ = velocity in the line of sight at the time of periastron passage,

T = time of periastron passage,

$2a$ = major axis,

i = inclination,

μ = mean motion,

U = period, so that $\mu = \frac{2\pi}{U}$.

The following formulæ are used in the computation:

$$\sin u' = \frac{2\sqrt{AB}}{A+B}, \quad \cos u_1 = \frac{A-B}{A+B},$$

$$e \sin \omega = \sin u_1 \frac{z_2 + z_1}{z_2 - z_1}, \quad e \cos \omega = -\cos u_1,$$

$$\left(\frac{dz}{dt}\right) = \frac{A+B}{2}(1+e)\cos\omega,$$

T is the abscissa corresponding to $\left(\frac{dz}{dt}\right)$.

$$a \sin i = 43{,}200 \frac{A+B}{\mu}\sqrt{1-e^2}.$$

in parts of the paper relating to the graphical construction, where a change of units did not seem to be desirable.—EDS.

[2] R. LEHMANN-FILHÉS, *A. N.*, 3242, **136**, 16–30.

The ephemeris was computed by means of the following formulæ:

$$\frac{dz}{dt} = \frac{A+B}{2}\cos u + \frac{A-B}{2}.$$

$$\mu\,(t-T) = E - e\sin E.$$

$$\tan\frac{u-\omega}{2} = \sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}.$$

The values obtained are:

$$A+B = 21.40 \qquad z_0+z_1 = -\ 565$$
$$A-B = -\ 0.48 \qquad z_0-z_1 = -\ 2585$$
$$2\sqrt{AB} = 21.40$$
$$u_1 = 88^\circ.7 \qquad \left(\frac{dz}{dt}\right) = -\ 0^{g.m}.7 = -\ 5^{km}.2$$
$$\omega = 96^\circ.0 \qquad T = +\ 0.01\ \text{day}.$$
$$e = 0.22 \qquad a\sin i = 837{,}000 = 418{,}500^{g.m} = 3{,}105{,}000^{km}.$$

The periastron passage occurs on

1896, February 28.82 ± 2.91*n*.

If, with these elements, we compute the motion in the line of sight at the times of observation, we obtain the following table:

Number	u	$\frac{dz}{dt}$	Curve	Obs. + 7km.9
20	13°.8	+37km.6	+39km.0	+36km.4
22	27 .0	+34 .5	+37 .5	+30 .5
12	59 .2	+19 .3	+22 .7	+ 8 .8
14	68 .6	+13 .7	+15 .3	+10 .5
15	98 .0	− 6 .4	− 8 .8	− 1 .6
17	110 .0	−14 .5	−18 .8	−30 .3
31	159 .0	−37 .9	−38 .9	−39 .7
21	186 .6	−40 .3	−40 .0	−37 .1
23	208 .4	−35 .8	−36 .7	−32 .4
13	215 .2	−33 .5	−35 .2	−30 .1
28	246 .6	−16 .6	−19 .2	−23 .4
30	255 .8	−10 .6	−12 .2	− 8 .6
18	261 .6	− 6 .7	− 8 .0	−17 .9
19	274 .0	+ 1 .9	+ 2 .5	+ 9 .6
24	297 .0	+17 .1	+16 .8	+16 .5
25	303 .0	+20 .7	+20 .9	+15 .1
26	311 .9	+25 .6	+26 .3	+23 .7
16	319 .2	+29 .2	+30 .1	+34 .0
27	329 .8	+33 .4	+34 .6	+25 .4
29	332 .8	+34 .4	+35 .3	+28 .2
32	354 .2	+38 .6	+39 .0	+42 .5

The points which were not used seem to form a group by themselves, and not to correspond at all to this curve. Only the points 8, 10, and 11 lie near it, while 3 has such a position that the curve is occasionally satisfied.

The cause of this discrepancy is probably that (as has already been remarked) the period 2.91 days cannot be used throughout the whole time covered by the observations. Hence a correction must be applied to the abscissæ of the points 7, 2, 4, 3, 5, 6, 9, and 1, and then a new curve drawn through these and the points previously considered.

The correction desired can be obtained graphically from the first curve. It is $0^d.32$. The corrected abscissæ are therefore :

1. $3^d.05$	7. $0^d.75$
2. 1 .70	8. 1 .75
3. 2 .22	9. 2 .66
4. 1 .51	10. 0 .78
5. 2 .59	11. 1 .79
6. 2 .66	

With these values we obtain :

Motion of system relative to Sun $= -1^{g.m}.40 = -10^{km}.4$

$z_1 = +\ 951 \quad A = 10.3 = 5^{g.m}.15 = 38^{km}.2$

$z_2 = -\ 1470 \quad B = 10.00 = 5^{g.m}.00 = 37^{km}.1$

$u_1 = 90^\circ.9 \quad \left(\frac{dz}{dt}\right) = -0^{g.m}.8 = -5^{km}.9$

$\omega = 94^\circ.0 \quad T = -0^d.07$

$e = 0.21 \quad a \sin i = 794{,}000 = 397{,}000^{g.m} = 2{,}946{,}000^{km}.$

The epoch of periastron passage is

1896, February, $27^d.74 \pm 2.91n$.

The following velocities have been computed with the aid of these elements :

No.	u	$\frac{dz}{dt}$	Curve	Obs. + $10^{km}.4$
1.....	$131^\circ.8$	$-25^{km}.7$	$-26^{km}.8$	$-16^{km}.4$
2.....	300 .4	+18 .5	+17 .8	+31 .0
3.....	353 .2	+36 .9	+37 .5	+32 .7
4.....	284 .4	+ 8 .8	+ 7 .8	+16 .0

No.	u	$\frac{ds}{dt}$	Curve	Obs. + 10km.4
5.....	47 .3	+25 .1	+28 .9	+29 .0
6.....	59 .6	+18 .5	+20 .8	+16 .5
7.....	226 .4	−26 .6	−30 .1	−23 .3
8.....	305 .0	+21 .1	+20 .0	+11 .7
9.....	59 .6	+18 .5	+21 .5	+26 .4
10.....	220 .6	−29 .2	−28 .9	−35 .0
11.....	308 .4	+22 .8	+22 .3	+ 9 .5
12.....	72 .8	+10 .6	+14 .1	+11 .3
13.....	220 .6	−29 .2	−28 .9	−27 .5
14.....	82 .4	+ 4 .4	+ 5 .9	+13 .1
15.....	111 .4	−14 .3	−16 .3	+ 0 .9
16.....	325 .4	+30 .5	+30 .1	+36 .5
17.....	123 .0	−21 .1	−24 .1	−27 .8
18.....	266 .2	− 3 .1	− 3 .7	−15 .4
19.....	278 .6	+ 5 .0	+ 5 .2	+12 .4
20.....	24 .8	+33 .6	+36 .4	+38 .9
21.....	193 .8	−37 .2	−36 .0	−34 .6
22.....	38 .8	+28 .8	+31 .5	+33 .0
23.....	214 .4	−31 .8	−31 .2	−29 .8
24.....	302 .6	+19 .7	+19 .3	+19 .0
25.....	308 .4	+22 .8	+21 .9	+17 .7
26.....	317 .8	+27 .4	+26 .7	+26 .3
27.....	337 .0	+34 .1	+34 .1	+27 .9
28.....	251 .0	−12 .8	−13 .0	−20 .9
29.....	340 .4	+34 .9	+35 .2	+30 7
30.....	260 .4	− 6 .8	− 6 .7	− 6 .1
31.....	168 .2	−37 .5	−36 .7	−37 .2
32.....	3 .0	+37 .1	+38 .2	+45 .0

The discrepancy which is exhibited by the velocities obtained in January and February when compared with all the others, as well as the different values of the period which they yield, cannot be explained with certainty at present. However, I should not wish to leave unmentioned a certain possible cause, which is a rapid motion of the line of apsides in the direction of the orbital motion of the star. Such a case is known to be possible when a disturbing force exists, due to a flattening of the central body, and the probability of this explanation is increased by Dunér's analogous investigation of the variable star Y Cygni, the unequal periods of which are explained by the motion of the line of apsides. It is hardly necessary to point out that in this case the available data are hardly sufficient to determine the amount of the motion.

PULKOWA, November 1896.

ON AN AUTOMATIC ARRANGEMENT FOR GIVING BREADTH TO STELLAR SPECTRA ON A PHOTOGRAPHIC PLATE.

By WILLIAM HUGGINS.

IN my original paper on the "Photographic Spectra of Stars" (*Phil. Trans.*, **171**, Part II, p. 672, 1880) I point out that the necessary breadth may be given to a photographic spectrum, without the use of a cylindrical lens, by simply causing the star's image to travel slowly in the direction of the length of the slit. At present it is usual, the length of the slit being fixed in the direction of the star's motion, by making the rate of the clock slightly fast, to cause the star to travel slowly along the slit, and when it has passed through a distance corresponding to the breadth which is desired for the photographic spectrum, by means of the slow-motion arrangements of the equatorial, to bring the star back to its first position; and in this way, by a sufficient number of runs of a fixed length, to make up the time of exposure which may be required. Without the assistance of an efficient electric control on the speed of the clock, this periodical bringing back of the telescope during a long exposure becomes very irksome, and brings in a serious loss of time. Even if the telescope is provided with a modern electric clock control, the method of successive runs by hand is troublesome and fatiguing, with the very long exposure so often necessary.

A few years ago an automatic arrangement suggested itself to me by which any desired amount of breadth could be given to photographic spectra with great precision and without interference by hand, except so far as may be required by change of refraction or from error of the clock rate. In this plan of working the clock must not be fast, but accurately adjusted to the motion of the stars, so that the star's image would remain fixed at any point of the slit at which it was put. Then, by means of an adjustable eccentric cam, introduced between the

clock and the driving screw, the stellar image is made to oscillate backwards and forwards about its mean position to any extent that may be desired. It is necessary to have the means of adjusting the amount of eccentricity to the breadth of spectrum desirable with the spectroscope which is in use; and also the means of removing, at pleasure, the eccentric motion when it is not required.

I took some spectra by this method some years ago, but the wheel which I then employed could not be made sufficiently eccentric. Recently I have had constructed a very simple eccentric arrangement which fulfils these conditions.

The clock-motion on its way to the driving-screw passes through two wheels gearing into each other, of the same diameter and of the same number of teeth. One of the wheels is provided with a cam by which the axis can be moved outside the center of figure of the wheel. This is effected by moving a small lever on the front of the wheel, which can then be fixed by a clamp in a position corresponding to any desired amount of eccentricity, or breadth of spectrum, within the range furnished by the cam. It is only necessary to bring back the lever to its first position, and to screw up the clamp, to make the wheel concentric, when the clock-motion will be transmitted to the driving screw without alteration of rate.

It is obvious that when the wheel is made eccentric, the star will slowly travel to and fro about its mean position. The time required to make a complete revolution in my instrument is about two minutes.

It should be pointed out that as the teeth of the eccentric wheel alternately approach and recede from the other wheel during each revolution, the teeth of both wheels should be long and suitably shaped, so as to allow of considerable interpenetration when the center of figure of the eccentric wheel is on the side of the axis which is nearer to the other wheel.

When such an eccentric wheel is employed the exposure increases towards the ends of the runs, that is, towards the two edges of the spectrum. If the unequal photographic action be

considered an objection, some other mechanical arrangement may be substituted for the eccentric wheel. For instance, a suitable automatic action upon the electric control of the clock, or upon a "mouse wheel." A simpler plan is to have both wheels of the pair concentric, but one of them furnished on one-half of its circumference with one tooth, or at most two teeth more, and on the other half with the same number of teeth fewer than the number required to transmit the clock-motion without alteration. The difference in the number of teeth would be too small to prevent good gearing of the wheels; and in this case the exposure would be uniform throughout the runs, and the photographs uniform throughout the breadth of the spectrum.

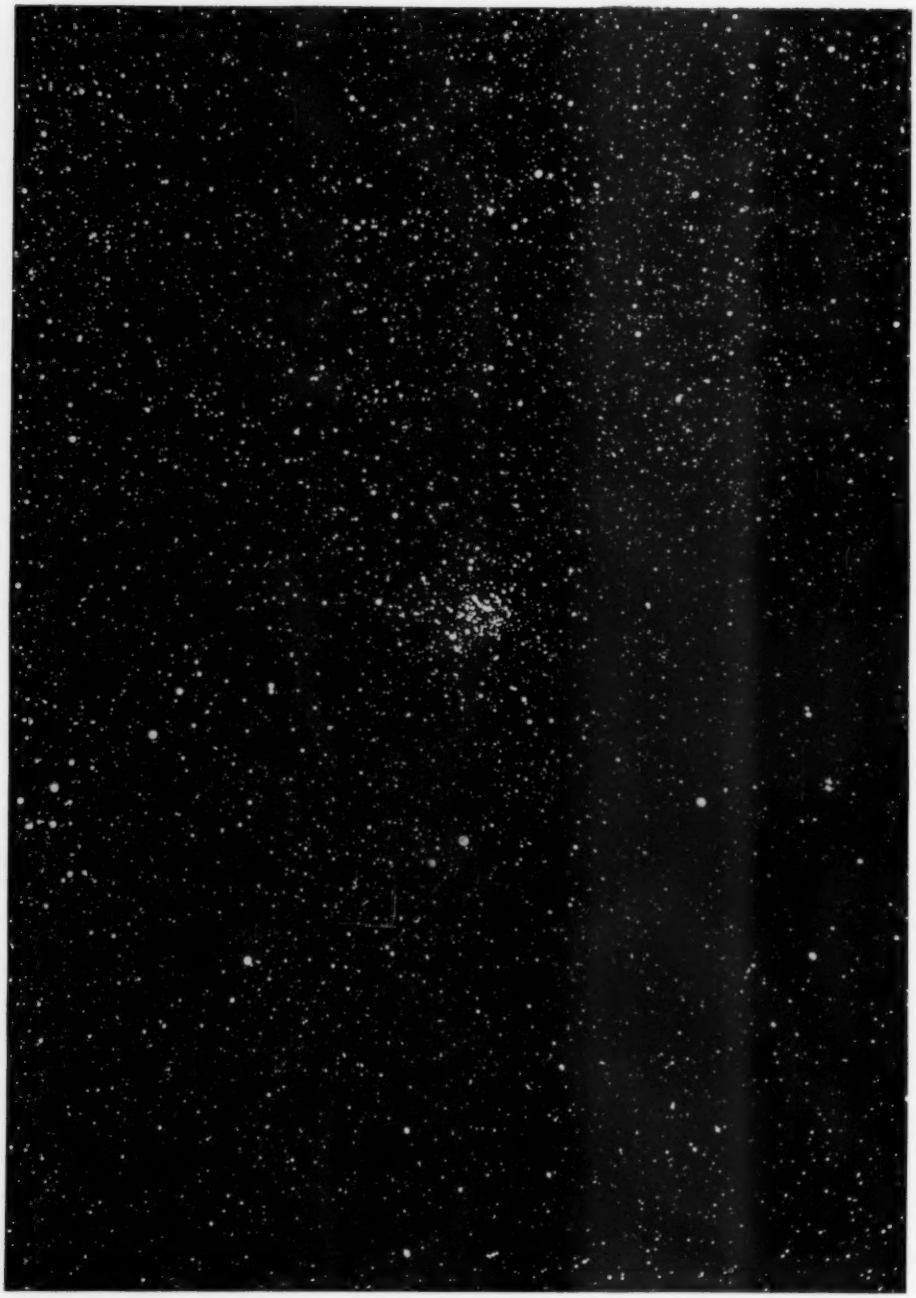
By the use of an automatic mechanical arrangement not only will the personal fatigue of the observer be greatly lessened, but, what is of no little importance in a variable climate, the necessary time of exposure will be reduced, for every moment of the exposure will tell upon the plate, since there will come in no interruptions of photographic action, through any want of immediate and accurate bringing back of the star at the end of each run, as can scarcely fail to be the case when it has to be done by hand.

LONDON, November 23, 1896.

PLATE II.

N

E



W

S

Enlarged twice

THE CLUSTER MESSIER 35

R. A. 6 hours 3 minutes; N. D. 24° 20′. Exposure 2 hours 10 minutes; 6-inch portrait lens

Lick Observatory Feb. 1, 1894. E. E. BARNARD

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVI.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3259.720		0	3265.454	Co	0 N
3259.834		0	3265.678		2
3259.977		0000 N	3265.762	Fe	4
3260.110	Cr, Fe	4	3265.822		00
3260.266		000	3266.016	V	1
3260.386 s	Mn, Ti- Fe	5 d?	3266.102		000
3260.593		0000	3266.275		000
3260.673		00	3266.362		000
3260.813		000 N	3266.561		00 Nt?
3260.950	Co	1	3266.798		3 N
3261.079		0000 N	3267.072		1
3261.186		00 N d?	3267.184		1
3261.319		0000 N	3267.328		00
3261.460	Fe	2	3267.391		000
3261.705	Ti	3	3267.561		00
3261.760		4	3267.661		0000 N
3261.938		00	3267.834 s	V	6
3262.142	Fe	2	3267.910	Mn	0000
3262.409	Fe- Sn	3	3268.186		1
3262.558		0000	3268.366	Fe	3
3262.838		0000 N	3268.468		0000
3263.023		3	3268.558		0000
3263.194		1	3268.644		00
3263.254		0000	3268.847	Mn	0000
3263.355	V, Co	0	3268.983		000
3263.491	Fe	4	3269.098		0
3263.587		0000	3269.207		000
3263.813	Ti	4	3269.355	Fe	1
3263.960		0 N	3269.462	Fe	00
3264.097		0	3269.555		0
3264.187		0	3269.627		0
3264.307		00 N	3269.747	Zr	0000 N
3264.405		1	3269.890		1
3264.528	Mo?	0	3270.033		000
3264.646	Fe	4	3270.089	Fe	2
3264.833	Mn	2	3270.265	-,Co	1 N
3264.906	Co	2	3270.473	Mn	00
3264.983		00	3270.656		0000 N
3265.176	Fe,-	3 d?	3270.794	Ti?	0
3265.310		0000	3270.872		0000 N

Wave-length	Substance	Intensity and Character	Wave length	Substance	Intensity and Character
3271.129	Fe	6	3278.221		000 N
3271.266	Ni, Co, Zr, V	5	3278.420	Ti	5
3271.436		0000	3278.574		0000
3271.536		0000	3278.687	Mn	1
3271.621	Fe	1	3278.867	Fe	3
3271.791	Ti, Fe	6d?	3278.974		00
3271.918	Co	0	3279.060	Ti	4
3272.085		0000 N	3279.279		1
3272.217	Ti	5	3279.400	Zr, Co	2
3272.367	Zr	2	3279.574		0000
3272.558		0000 Nd?	3279.644		0000
3272.729		1	3279.784		0
3272.855		0	3279.872	Fe	1
3272.971		0000 N	3279.973	V	1
3273.175	Mn Zr	2	3280.120	Ti	2
3273.311		0000	3280.256		000 N
3273.477		000	3280.392	Fe	4
3273.606		1 N	3280.493		0000 N
3273.758		0	3280.623		0000 N
3273.844		0000	3280.806	Ag	0
3273.970		0000 N	3280.900	Mn	1
3274.096 s	Cu	10	3281.100		0000Nd?
3274.350		1	3281.250		0 N
3274.575	Fe	3	3281.429	Fe	5
3274.677		0000	3281.652		0000
3274.800		0	3281.725		0000
3274.907		0000	3281.841		2
3275.033		1	3281.993	Ni	2 d?
3275.149		0000	3282.122		000
3275.276		0000	3282.372		00
3275.353		0000	3282.459	Ti, Zn	5
3275.423	Ti	3	3282.572		0
3275.529		0000	3282.665	V	1
3275.603		0000	3282.830	Ni	2
3275.716		000	3282.962	Ni	2
3275.809		1	3283.029	Fe	2
3275.969		0 N	3283.179		000
3276.103		000	3283.286		00
3276.259	V	5 d?	3283.332		00
3276.386		00	3283.458	Co	0
3276.594	Co, Fe	3	3283.576	Co,-	2
3276.741		1	3283.680	Fe	1
3276.905	Ti	3	3283.812		0000
3277.124	Ti	2	3283.929		00 N
3277.225		0000	3284.059		00
3277.315		0	3284.116		00
3277.482	Co-Fe	7 d?	3284.256		0000 N
3277.795	Co	0 N	3284.366		0000
3277.848		0 N	3284.489		0000
3277.997		0 N	3284.559	Ni	1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3284.648		0	3290.375		00
3284.723	Fe	2	3290.475		0000
3284.847	Zr	1	3290.602		00
3284.968		0000	3290.642		0 N
3285.148		0 N	3290.765		000
3285.324		1	3290.842	Fe	2
3285.421		0	3291.119	Fe	4
3285.547	Fe	2	3291.261		0 N
3285.678		00	3291.411		0900
3285.828		0000	3291.557		00
3285.908		0000	3291.671		000
3286.034	Fe?, Ti?	000 N	3291.824	Fe	00
3286.164		2	3291.897		1
3286.197		0	3292.151 } s	Fe	4
3286.310		0000	3292.206 } s	Ti, Co	3
3286.384		000	3292.337		0000 N
3286.494		0000	3292.451		0
3286.580		1	3292.636		0
3286.667		00	3292.728	Fe	4
3286.784		0	3292.870		0000 N
3286.898	Fe	7 N	3292.996	Mn?	000
3286.980		0 N	3293.053		00
3287.086	Ni	3	3293.276	Fe, Co	2
3287.224	Fe	2	3293.350		0000
3287.347	Co	2	3293.605		00
3287.460	Zr?	000	3293.800	Fe	1
3287.560		000	3293.900		00
3287.597		000	3293.989	Co?	000 N
3287.709		0000	3294.125		0000 N
3287.793 s	Ti	5	3294.235		0000 N
3287.863		0000	3294.325		000 N
3287.986		0000 N	3294.462		0000 N
3288.175		0	3294.569		0000 N
3288.281	Ti	3	3294.682		0000
3288.453	Fe	00 N	3294.749	Co	00
3288.561	Ti	2	3294.849		000
3288.705	Ti	2	3294.949		00 N
3288.801	Fe	1	3295.069	Ti	0
3288.939	Zr	0	3295.149		0000
3289.103	Fe	2	3295.243		0
3289.153		0	3295.375		1
3289.272		0000	3295.562		2
3289.372		0000	3295.732		000
3289.498		4	3295.762		0000
3289.568	V	3	3295.951 s	Fe, Mn	6
3289.705		0000 N	3296.168	Mn?	00
3289.875		0000	3296.388		1 N
3289.988		000	3296.504	Zr?	000 N
3290.035		000	3296.602	Fe	2
3290.238		0000 N	3296.721		0000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3296.948		1	3302.895		0000
3297.014	Mn	1	3302.990		3
3297.194		0 N	3303.109 s	Na	5
3297.301	Co	0	3303.248	La	000 Nd?
3297.381		0	[1] 3303.398	Mn	00 N
3297.511		000	[1] 3303.601 } s		3
3297.644		000	3303.698 }	Fe	2
3297.720		000	3303.908		000
3297.793		000	3304.022		0000 N
3297.963		0 N	3304.263		000
3298.009		1	3304.375	Mo?	1
3298.140		0000	3304.492		0
3298.268	Fe, V, Di	5	3304.577		000
3298.361	Mn	000	3304.611		000
3298.451		0000	3304.719		00
3298.545		0000	3304.881		00 N
3298.685		1	3305.001	Mn	00
3298.818	Co	2	3305.089	Ni	1
3298.869	V	3	3305.194		000
3298.995		0000	3305.283	Co-Zr	2
3299.211		1	3305.354		000
3299.305		0000	3305.434		0000
3299.477		0000	3305.541		0000
3299.564	Ti	2	3305.604		0000
3299.652	Mn	0 Nd?	3305.754		000 N
3299.804		0	3305.877	Co	0
3299.905		0	3305.991		2
3300.017		000	3306.105 s	Fe	4 N
3300.204		0000 N	3306.221		2 N
3300.297		00 N	3306.296		0000
3300.444		0000 Nd?	3306.412 } s	Zr	2
3300.617		000	3306.506 }	Fe	4
3300.687		0000 N	3306.623	Co	1
3300.802		000	3306.726		1
3300.944		0000	3306.830		000
3301.039		000	3306.903		0000
3301.143		0000 N	3307.010	Ti	00
3301.263		0000 N	3307.114	Mn	1
3301.352	Fe	1	3307.165	Fe	2
3301.552	Fe	0	3307.280	Co	1
3301.706		0000	3307.374	Fe	1
3301.808	Ti, Sr	1	3307.473		0000
3301.909		0000	3307.636	Sr?	000 N
3301.996		0000	3307.845	Fe	4
3302.055	Fe	0	3308.035		00 N
3302.232	Ti, Pd	4	3308.239		0 N
3302.289		0000 N	3308.405		0000
3302.443		0000 N	3308.527	Ti	0
3302.510 s	Na	6	3308.619	Co	00
3302.720	Zn	1	3308.749		000

[1] A zinc line comes between these two.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3308.888 } s	Mn	2	3314.476		000 N
3308.947 }		5	3314.574	Ti, Fe, Mn	3 N
3309.065	Co, Ti	0000 N	3314.663	Ti	2
3309.159		0000	3314.742		000 N
3309.212		0000	3314.876	Fe	4
3309.325		0000 N	3314.995	Mn	0
3309.452		0000 N	3315.178	Co	000 N
3309.558	Ni	0	3315.303		0
3309.658	Ti,-	2 N	3315.385		0000
3309.851	Ti	00 N	3315.457	Ti	3
3309.974		0000	3315.548		0
3310.031		0000	3315.685		0000 N
3310.158		000	3315.807	Ni	7 d?
3310.248		0000	3316.081		0000
3310.338	Ni	2	3316.128		0000
3310.472	Fe	3	3316.325		000 Nd?
3310.626	Fe	2	3316.467		00
3310.777		1 N	3316.561	Mn	0
3310.996		0	3316.615		0000
3311.041		000	3316.698	Mn	00
3311.051		0000	3316.778		00
3311.238		0	3316.871		00
3311.343		00	3316.980		0
3311.477		000	3317.034		0000
3311.587		00	3317.174		00
3311.727		0000	3317.262	Fe	2
3311.843		000	3317.393	Mn	1
3312.023		0	3317.514		0
3312.063	Mn	2	3317.720		0
3312.187		0000	3317.830		0000
3312.325	Fe-Co	3 d?	3317.960		0000
3312.453	Co	2	3318.160 s	Ti	6
3312.563		00	3318.339		000
3312.729		1	3318.496	Ti-Co	1 Nd?
3312.827	Ti, Fe	2	3318.645	Zr	00
3312.970	Co	000	3318.741		000 N
3313.053		000	3318.895		00
3313.137	Ni	1	3319.035		0000Nd?
3313.206	Co	000	3319.172	Zr	0
3313.301	Mn	00	3319.207		1
3313.432		0000 N	3319.298	Co	00
3313.562	Mn	00	3319.387	Fe	2
3313.676		000 N	3319.491		000
3313.774		1	3319.619	Co	1
3313.853		0	3319.673		0
3313.929		0000	3319.815		0000
3314.042		00 N	3319.953	Co	0
3314.124		1	3320.032		0
3314.214	Co	1	3320.161		0000
3314.334	Mn	0	3320.258		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3320.391	Ni	7	3326.335		00
3320.508		0000	3326.432		000
3320.621		0000	3326.553		0
3320.783	Mn, Fe	2	3326.727		0 N
3320.907	Fe, Ni	1	3326.825	Co	1
3321.044		0000	3326.907 [1]	Ti	5
3321.177	Be?	0000 N	3326.998 [1]		3
3321.324		000	3327.127	Co	1
3321.366		0	3327.297		00
3321.494		0000	3327.424		0000
3321.550	Be?	000	3327.533	Ni	2
3321.667		00	3327.633	Fe	1
3321.715	Ti	00	3327.757		000
3321.836	Ti,	4	3327.861		0000 N
3322.047		000 N	3328.016	Di?	2
3322.190		0000	3328.101		0
3322.331	Co	1 Nd?	3328.341	Co	00
3322.454	Ni	3	3328.487		2
3322.610	Fe	2	3328.605		0
3322.784		00	3328.713		0000
3322.833		00	3328.849	Ni	1
3323.003		1	3328.933		0000
3323.056 [1]	Ti	5	3329.000	Fe	3
3323.116 [1]		3	3329.186	Cr, Fe	1
3323.213		1	3329.233		000
3323.256		00	3329.338		0000
3323.426		0000	3329.435		0000 N
3323.524		1	3329.568 [1]	Ti, Co	5
3323.669		0	3329.648 [1]		3
3323.881	Fe	3	3329.762	Fe	0000 N
3324.049		000	3329.902		00
3324.129		0	3329.982		000
3324.201		4 N	3330.044	Mg	3
3324.280		0	3330.102		2
3324.494	Fe	1	3330.212	Sr?	000
3324.674	Fe	3	3330.364		0
3324.808		0	3330.438		1
3324.921		1	3330.565		0000 N
3325.142		0	3330.645		000
3325.168		0000	3330.745	Sn?	000
3325.288		0000	3330.802	Mn	00
3325.381	Co	1	3330.914		000
3325.462		000	3331.056		1 N
3325.609	Fe	3	3331.194		000 N
3325.712		000	3331.384		00 N
3325.820		0000	3331.527		000
3325.886		0000	3331.747 s	Fe	2
3326.028		000	3331.915	Fe	2
3326.105		0000	3332.061		000 N
3326.212		0000	3332.184		0

[1] See note to 3335.192, 3335.350, etc.

Wave length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3332.240	Ti	3	3338.054[1]		0
3332.326	Mg	3	3338.141		0000
3332.421		000 N	3338.247		0
3332.481		00	3338.368		000
3332.707		0000 N	3338.478		000
3332.850		0000	3338.561		000
3332.965		0	3338.651	Co	00
3333.026		0000	3338.759	Fe	2
3333.160		000	3338.905		0
3333.250		0	3338.944		0000
3333.353		000 N	3339.051		0000 N
3333.526	Co	2	3339.180	Ni?	1
3333.728		1	3339.333	Fe	2
3333.854		0	3339.438		000 N
3333.953		000	3339.577		000 N
3334.046		000	3339 713	Fe	1
3334.116		000	3339.818		1
3334.266	Co	4	3339.932	Co, Cr	3
3334.356	Fe	1	3240.011		1
3334.406	Zr?	1	3340.173		000 N
3334.613		0	3340.310		0000 N
3334.753	Zr	0	3340.464[1]	Ti	3
3334.846		0	3340.523[1]		2
3334.933		0000 N	3340.702	Fe	2
3335.065		000 N	3340 823		00 N
3335.192		0000 N	3340.957		0000 N
3335.299[1]	Ti	4	3341.027		1
3335.350[1]		2	3341.137		0000
3335.439		1	3341.300		0000 N
3335.553		1 N	3341.417		0000
3335.666		2 N d?	3341.480	Co	00
3335.859		1	3341.583		0000
3335.915	Fe	2	3341.690		0000
3335.979		000	3341.820		000
3336.054		0	3341.967[1]	Ti	4
3336.259		0	3342.062[1]	Fe,-	4
3336.391	Fe	2	3342.280		0
3336.477	Cr	2	3342.358	Fe, Ti	3
3336.635		00 N	3342.442	Fe	3
3336.679		00	3342.506		0000
3336.820	Mg	8 N	3342.606		0000
3336.962		0 N	3342.717	Cr	3
3337.098		0	3342.829	Ti	00
3337.138		1	3342.892	Co	00
3337.319	Co	1 N	3343.032		00
3337.471		0000	3343.156		00
3337.524		000	3343.366		0
3337.630	La	0	3343.479		00
3337.803	Fe	3	3343.656		000 N
3337.984[1]	Ti	2	3343.804	Mn	1

[1] There are several cases like this where there is a close double, one line at least belonging to Ti. It is not certain in such cases that both are not Ti lines. Possibly the second may be Ti and not the first. The notes do not yet settle these cases, except 3314.573 and 3314.663, when both lines belong to Ti.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3343.908	Ti	4	3349.965		0000
3344.036		0000 N	3350.080		000 N
3344.215		000 N	3350.214		000 N
3344.315		00	3350.347		2
3344.521		0000 N	3350.429		1
3344.655	La	2	3350.512		1
3344.721		0000	3350.545	Di?	1
3344.831		0000 N	3350.648	Ti	2
3344.924	Zr	0	3350.985		000
3345.015		000	3351.089		000
3345.068		2	3351.201		00
3345.156	Zn	2	3351.289		0000
3345.298		0000 N	3351.379		0000
3345.495	Mn	00	3351.472		0000
3345.618		000	3351.551		0000
3345.715	Zn-	1	3351.658	Co-Fe	2
3345.761		00	3351.745	Cr	0
3345.835		00	3351.884 s	Fe	1
3345.955		000 N	3352.101	Cr	0
3346.047		000 N	3352.198	Ti	2
3346.154	Cr, Zn	0 N	3352.318		0000 N
3346.284		00	3352.578		000 N
3346.414		00	3352.771		00 N
3346.557		0	3352.908		000
3346.734		0000 N	3352.958		000
3346.860[1]	Cr	3	3353.065	Ti, Fe	1
3346.904[1]	Ti	2	3353.262		2
3347.066	Co	2	3353.402	Fe	1
3347.157		0000	3353.538		000 N
3347.267		0000 N	3353.661		0000 N
3347.450		000	3353.768	Zr	00 N
3347.507		000	3353.875		4
3347.638		0	3354.057		000 N
3347.760		00 N	3354.199	Fe	2
3347.970 s	Cr	3	3354.350	Co	00 N
3348.072 s	Fe	3	3354.523	Co, Zr	3
3348.254	Co	1	3354.670		00
3348.370		0000 N	3354.778	Ti	3
3348.520		0000 N	3355.023		00 N
3348.673		000	3355.197		0000 N
3348.820		000	3355.363	Fe	4
3349.043	Ti	4	3355.497		0000 N
3349.135	Ti, Cr	3	3355.661	Mn	0
3349.212	Ti	2	3355.797		0000 N
3349.399		00	3355.957		000 N
3349.519	Cr	2	3356.080		000
3349.597	Ti	7	3356.231 s	Zr	1
3349.695		00	3356.370		000 Nd?
3349.785		00	3356.462		2
3349.874		0	3356.548	Fe	2

[1] See note to 3335.299, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3356.676	Co	000 N	3362.402		2 d?
3356.821	Fe	2	3362.528		0
3356.976		000	3362.727		0000
3357.092		0000	3362.782		1
3357.256		000 N	3362.936	Co	4 Nd?
3357.412	Zr	**2**	3363.107		0
3357.537		1	3363.298		0000 N
3357.703		0	3363.442	Co	0 d?
3357.816		0000	3363.542		1
3357.874		0	3363.750	Ni	1
3357.959		00	3363.854		1
3358.076		0000	3363.955	Co	0
3358.182		1 N	3364.055		0
3358.276		0000	3364.148		00
3358.416	Ti	3	3364.232		0000
3358.542		00	3364.362		00
3358.649	Ti-Cr	4	3364.408	Co	1
3358.771		00	3364.535		0 Nd?
3358.832		0	3364.749	Ni,-	3 d?
3358.929		00	3364.832		00
3359.035		2 N	3365.081		0000
3359.144		00	3365.167		0000
3359.248	Ni	3 N	3365.247		0000
3359.420	Co	1	3365.341		00
3359.542		1	3365.451		0000 N
3359.636	Fe?	2	3365.581		0
3359.769		1	3365.684		00
3359.823		2	3365.908	Ni	6
3359.936		1 N	3366.127		000
3360.066		0	3366.311	Ti, Ni	6 d?
3360.181		2	3366.494		000
3360.258		0	3366.594		000
3360.345		0	3366.687		0000
3360.444	Ni	2	3366.791		0000 N
3360.485	Cr	1	3366.931	Ni, Fe	3
3360.631		0	3367 009	Fe	3
3360.741		0	3367.117		000
3360.828		0	3367.233	Co	2
3360.988		0	3367.297	Fe?	1
3361.055	Ti	1	3367.434		00
3361.141		0	3367.527		0000
3361.241		1	3367.575		0
3361.327	Ti	8	3367.687		0
3361.421		2	3367.812		0
3361.568		0 N	3367.953		000
3361.704	Co,-	3 Nd?	3368.029	Ti, Ni, Fe	2
3361.906		1	3368.193	Cr,-	5 d?
3361.988		0	3368.319	Mn	1
3362.087	Ti	2	3368.382		000
3362.275		1	3368.496		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3368.580		0000	3374.271		000
3368.680		00	3374.358	Ni	4
3368.793		00	3374.487	Ti, Co	2
3368.860		00	3374.588	Fe	1
3368.956		0	3374.778	Ni	2
3369.083		3 d?	3374.872	Zr	1
3369.190		0	3374.981		000
3369.286		0	3375.068		0
3369.352	Ti, Mn	1	3375.231		00
3369.506		0 N	3375.351		0000
3369.633		0	3375.478		0 N
3369.713	Fe, Ni	6	3375.601		0000
3369.800		1	3375.698	Ni	1
3369.932		0	3375.768		000
3370.052		0	3375.866		0
3370.173		00	3375.991		0000
3370.330		0 N	3376.081		0000
3370.468	Co	2	3376.164		00
3370.584	Ti	2	3376 238		000
3370.770	Zr, Mn	1 Nd?	3376.341		0000
3370.933	Fe	4	3376.414		0
3371.020		000	3376.471	La	2
3371.110		0	3376.630	Fe	2
3371.246		00	3376.731		0000
3371.296		00	3376.814		0000
3371.431		0	3376.894		000
3371.535		00	3376.978		000
3371.593	Ti	3	3377.084		0000
3371.745		000	3377.202	Co	0 N
3371 852		00	3377.408		00
3371.899		00	3377.497		0000
3372.124	Ni,-	4	3377.622 } s	Ti	3
3372.225	Fe	1	3377.723 }	Ti	3
3372.314		0	3377.837		0000 N
3372.362	Ti	2	3377.943		0000 N
3372.488	Fe	0	3378.114		1
3372.609	Fe	00 N	3378.203		000
3372.759		0 N	3378.320		00
3372.901	Ti-Pd	{ 5	3378.476	Cr, Co?	2
3372.994		{ 5	3378.723		00
3373.105		0 N	3378 824	Fe	2
3373.229		000	3378.881	Co	1
3373.369	Co	0	3379.005	Mn	0 N
3373.452		0	3379.161	Fe	2
3373.555	Zr	0	3379.337	Ti, Cr	2 d?
3373.642		0	3379.514	Cr	2
3373.742		0000	3379 577		000
3373.872		0000	3379.687		0000
3374.016	Fe	1	3379.783		0000
3374.119		2	3379.843		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3379.961	Cr	3	3385.577	Fe	1
3380.060	Zr, Ti	1	3385.688	Fe	1
3380.157		0000	3385.809	Ti	1
3380.255	Fe	3	3385.861	Fe?	00
3380.397[1]	Ti	3	3386.005		0000 N
3380.450[1]		3	3386.085	Ti, Mn	3
3380.605		0	3386.310		00 N
3380.722	Ni	6 N	3386.408		000
3380.889	Sr?	1	3386.488		000
3381.026	Ni, La	5 Nd?	3386.588		000
3381.202		0000	3386.691		00 N
3381.269		1	3386.875		000
3381.490	Fe	2	3386.921		000
3381.632		000	3387.014		000
3381.669		000	3387.194		000 N
3381.786		0000	3387.307		000
3381.896		000	3387.444		0
3382.002		000	3387.554	Fe	2
3382.129	Mn	0	3387.600		0
3382.224		00 N	3387.762	Fe	1
3382.340		0	3387.854		00
3382.450	Ti	1	3387.988	Ti-Zr	5 d?
3382.549	Fe	2	3388.190		0000
3382.604	Di?	1	3388.311	Co	3
3382.724		000	3388.473	Zr	1
3382.825	Cr, Mn	4	3388.604		0 N
3382.926		0000	3388.761	La?	1
3383.036		00	3388.896	Ti	2
3383.129		0	3388.994		00
3383.232		0000 N	3389.107		1
3383.342		0000 N	3389.257		000
3383.449	Ag	000	3389.387		00
3383.512		0	3389.460		00
3383.629		000 N	3389.540		0
3383.709		0	3389.747		0000 N
3383.833	Fe	3	3389.884 s	Fe	2
3383.951	Ti	3	3389.960		0000
3384.133	Fe	3	3390.060		0000
3384.225		00	3390.154		000
3384.375		000	3390.244		000 Nd?
3384.461		000	3390.400		00
3384.561		000	3390.544		00
3384.728		0000 N	3390.654		000
3384.782		00	3390.736		000
3384.908		1	3390.819	Ti	0
3385.061		0000	3390.919		00
3385.167		0	3391.033		00 N
3385.215		000	3391.175	Ni	5
3385.361	Co	3	3391.243		1 N
3385.468		0000	3391.409		0000 N

[1] See note to 3335.299, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3391.509		0000 N	3397.451		0000
3391.578	Cr	2	3397.571		00
3391.726		0	3397.691	V?	1
3391.806		0000 N	3397.779	Fe	2
3391.977		0	3397.931		00
3392.109	Zr	2	3397.974		000
3392.153	Fe	1	3398.151		0000 N
3392.259		0	3398.244		0000 N
3392.441	Fe	3	3398.357	Fe	1
3392.633		00 N	3398.441		00
3392.759	Fe	2	3398.511		0
3392.813		1	3398.551		0000 N
3392.926	Ti	0	3398.746	Ti	00 N
3393.029		0	3398.839		000
3393.113	Ni	3	3398.949		000
3393.160	Cr	1	3399.059		0
3393.285	Zr	1	3399.126		0000
3393.427		0	3399.294		00
3393.526	Fe	1	3399.376	Fe, Zr	2
3393.845		1 Nd?	3399.489	Fe	3
3393.980	Cr	2	3399.654		0
3394.062	Fe	1	3399.746		0000
3394.220	Fe	1	3399.942		0 N
3394.432	Cr	2	3400.153		0000 N
3394.518	Fe	0	3400.279		000
3394.685	Ti	3	3400.366		0000
3394.746	Fe	3	3400.529		000
3394.875		0000	3400.629		0000
3394.958		0000	3400.779		1
3395.085		0000 N	3400.979		0000
3395.212		0	3401.121		1
3395.408		00 N	3401.307	Ni	1
3395.505	Co	3	3401.478		000
3395.544		2	3401.664	Fe	3
3395.750		0	3401.778		0000 N
3395.882		0	3401.900		0
3396.012		000	3401.992		000
3396.125		0	3402.058		000
3396.178		0	3402.208		000
3396.320	Ni	1	3402.262		000
3396.437		0	3402.352		000
3396.523		0	3402.400	Fe	3
3396.642		000	3402.553	Ti	3
3396.742		0000	3402.685		0
3396.792		00	3402.842		0000
3396.965		0000	3402.925		000
3397.062		0000	3403.033		0
3397.116	Fe	3	3403.145		0000 N
3397.197		0000	3403.288		0000 N
3397.356		1	3403.404	Cr	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3403.478	Fe, Ti	2	3409.346	Fe	2
3403.572	Ni	2	3409.530		000 N
3403.725		000 N	3409.711	Ni	2
3403.826		0	3409.803		0
3403.925		0000	3409.950	Ti	2
3404.005		0000	3410.080		00
3404.128		0000	3410.170		1
3404.202		000 N	3410.313	Fe	2
3404.292		0000	3410.386	Zr	1
3404.413	Fe	2	3410.526		0000 N
3404.511	Fe	3	3410.696		00
3404.581		0000 N	3410.783		0000 N
3404.717	Pd	0	3410.923		00
3404.897		1	3411.035	Fe	2
3404.972	Zr	0	3411.160		00 Nd?
3405.044	C?	0	3411.274	Fe	1
3405.097		00	3411.366		0000
3405.217 } s	Co	2	3411.498	Fe	3
3405.302 }		2	3411.700		0000
3405.504		000	3411.883		000
3405.637		0000	3412.009		000
3405.716	Fe	0	3412.109		000
3405.837		0000 N	3412.162		0000
3405.971	Fe	1	3412.302		0000 N
3406.111		000 N	3412.481	Co	5
3406.254		00	3412.595		0000
3406.304		00	3412.775	Co	4
3406.391		0000	3412.909		0000 N
3406.491		0000	3413.019		000
3406.572 s	Fe	3	3413.275	Fe	5 d?
3406.697		0	3413.402		000 N
3406.943 s	Fe	5 d?	3413.542		00
3407.187		000	3413.597	Ni	2
3407.338	Ti	2	3413.651		2
3407.447		2	3413.782		0
3407.537		00	3413.855		00
3407.597	Fe	4	3413.935		0000
3407.693		3	3414.079	Ni	4
3407.844		0000 N	3414.269		00 N
3407.937	Di?	0	3414.399		000 N
3408.091		00 Nd?	3414.535		000 N
3408.217		0	3414.643		1
3408.317		0000 N	3414.769		1
3408.484		0000 N	3414 911	Ni	15
3408.637		000 Nd?	3415.050		1 Nd?
3408.811		000 N	3415.230		0
3408.911	Cr	3	3415.279		00
3409.070		1	3415.462		0000 N
3409.210		0000	3415.575		0000
3409.302	Co	2	3415.672	Fe	3

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3415.815		0	3422.033		0000
3415.922		00 N	3422.087		0000
3416.029		0000	3422.260		1
3416.164		3	3422.347		0000
3416.274		0000	3422.468	Ni	1
3416.421		1	3422.629	Fe	4
3416.541		0000	3422.794	Fe	3
3416.644		000 N	3422.892	Cr	4
3416.771		00	3423.016	Ni	1
3416.808		0	3423.153		0000 N
3416.914		00	3423.307		000 N
3417.001		00	3423.380		00 N
3417.095	Ti	1	3423.453		000 N
3417.198		00	3423.667		00 N
3417.301	Co	3	3423.760		0 N
3417.401	Fe	1	3423.848	Ni	7
3417.491		000	3423.972		0 N
3417.618		0000	3424.127		0
3417.681		0000	3424.311		00
3417.819	Co	00	3424.432	Fe	4
3417.948	Fe	2	3424.579		0000 N
3418.002		2	3424.646	Co	0
3418.161		0000	3424.732		000
3418.303	Fe	1	3424.846		000
3418.448		0000 N	3424.966	Zr	00
3418.654	Fe	5	3425.152	Fe	4
3418.864		000 N	3425.196		000
3419.013		1	3425.432		0000 N
3419.108		0000 N	3425.579		0000 N
3419.282	Fe	1	3425.716 s		2
3419.424		000 N	3425.879		0000 N
3419.554		000 N	3425.976		00
3419.836	Fe	2	3426.102		000
3420.013		000	3426.226		000
3420.133		000	3426.349		0000
3420.240		00	3426.466	Fe	3
3420.360		000	3426.535	Fe	3
3420.417		00	3426.769	Fe	3
3420.575		0	3426.867		2
3420.620		00	3426.929		0000
3420.730		000	3427.046		0000
3420.880	Ni?	2	3427.126	Fe?	2
3420.940	Mn	00	3427.263 s	Fe	3
3421.147		000	3427.340		1
3421.253		0000 N	3427.492		0000
3421.353	Ni, Cr, Pd	4	3427.596		0000
3421.482	Ni	2	3427.656		00
3421.620		0000 N	3427.746		0000 N
3421.758	Co	0	3427.899		000 N
3421.860		0	3427.972		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3428.082		0000 N	3434.117		0000
3428.154		0	3434.183		0
3428.341	Fe, Co	4	3434.259		0
3428.459		0000	3434.383		0000
3428.561		1	3434.512		000
3428.626		1	3434.626		0000
3428.776		000	3434.746		0000
3428.892	Co	2	3434.829		0000
3429 066		000	3434.962		000
3429.172		0000	3435.032		000
3429.282		0000 N	3435.102		00
3429.468		00	3435.179		0000 N
3429.605		0000	3435.296		000 N
3429.718		0000 N	3435.382		000 N
3429.851		00	3435.509		0000 N
3429.951		000	3435.628		1
3430.071		0000 Nd?	3435.729		00
3430.218		0000 N	3435.819	Cr	0
3430.295		000	3435.962	Cr	0 N
3430.428		00	3436.174		1
3430 545		00 N	3436.250		0
3430.671	Zr	1	3436.332	Cr	2
3430.777		0000 N	3436.472		0000 N
3430.870		0000 N	3436.552		000 N
3431.020		000	3436.666		0000 N
3431.090		000	3436.786		0000
3431.207		0000	3436.882		000
3431.320		0000	3436.976		0000 N
3431.423		00	3437.116		000 N
3431.590		0000 N	3437.190	Fe	3
3431.721	Co	4	3437.282	Zr	00
3431.830		000	3437.427	Ni	5 d?
3431.965	Fe	3	3437.616		0000Nd?
3432.077		000	3437.772		00
3432.157		0	3437.829		00
3432.270		000	3437.926		0000
3432.350		0000	3438.012		0000
3432.447	Co	0	3438.094	Fe	2
3432.550		00	3438.236		000
3432.707		0000	3438.376	Zr	2
3432.863		0	3438.455	Fe	1
3433.023		000	3438.556		0000 N
3433.163	Co	3	3438.639		000 N
3433.212	Cr, C?	2	3438.851		000 N
3433.290	Pd	0000	3439.092	Mn?	2
3433.453	Cr	3	3439.171	Fe	2
3433.591		0	3439.268		0000 N
3433.715	Ni, Cr	8 d?	3439.365		000 N
3433.905		0 N	3439.478		00 Nd?
3434.053		0000	3439.635		000 N

ON THE APPLICATION OF INTERFERENCE METHODS TO THE DETERMINATION OF THE EFFECTIVE WAVE-LENGTH OF STARLIGHT.

By GEORGE C. COMSTOCK.

THE experiments to be set forth in the present paper grew out of and are collateral to an investigation of the atmospheric refraction contained in *Publications of the Washburn Observatory*, Vol. IX. The discussion of those observations, pp. 185–190, seemed to show a sensible difference in the amount of the refraction, depending upon the color of the star in question, a difference which might indeed be expected *a priori* since, the color being produced by selective absorption in the stellar atmosphere, it may be assumed that the average wave-length and the corresponding refraction of the light received from a red star will be in some measure different from that of a star in whose spectrum the violet and blue rays have not suffered an absorption relatively so great.

But since the colors thus produced cannot, in general, be saturated and will usually be quite different from the pure spectral colors, the average wave-length of the light of a given star must not be assumed to be even approximately determined by matching its color, as nearly as may be, with that of a definite part of the solar spectrum, and the same holds true, *a fortiori* for the effective wave-length if we understand by that term the wave-length of that part of the stellar spectrum which the observer adopts as determining the position of the star and upon which his attention is concentrated in the observing. It does indeed result, at least apparently, from the investigation above cited that the wave-lengths determined for the stellar colors there encountered are approximately those of corresponding colors in the solar spectrum and, erroneously as I now think, I have regarded this agreement as a confirmation of the reality of the color effect there investigated.

Recognizing that no very considerable weight can attach to a determination of the color effect made as was the above, I have endeavored to supplement and control it by an entirely independent method, which should give immediately a determination of the effective wave-length of the light of a given star. The term effective wave-length as above defined is nearly equivalent to the wave-length of the (visually) brightest part of the star's spectrum, it being assumed that in ordinary visual observations the observer's attention is concentrated upon this part of the spectrum into which the atmosphere transforms the stellar image.

This assumption is perhaps open to question in the case of very bright stars, but these may be reduced to the case above considered by the use of screens or other appropriate device for diminishing their brightness, recourse to which is frequently had upon quite other grounds.

The value of such determinations of effective wave-length for the more refined investigations of the astronomy of position is apparent and is frequently noted in connection with the determination of the solar parallax from observations of the planets, but little attention has hitherto been paid to a quantitative determination of the color effect. In the literature of the subject accessible to me I have been able to find only one attempt at a determination of effective wave-lengths which can be designated as in any degree successful (Schwarzschild, *A. N.*, No. 3335), and that is limited to a consideration of the mean result furnished by a large number of stars taken without regard to individual differences. The investigations of von Konkoly (*Observatory*, **4**, 11) upon the relation of color to wave-length are directed to a different end and his numerical results, which are based upon a comparison of the saturated colors of a Geissler tube with the dilute colors of five stars, give no clue to their effective wave-lengths, as the term is here employed.

As a means of dealing with the problem of differences in effective wave-length I have had recourse to methods based upon the interference of light produced by placing between the star

and the observing telescope (the 40^{cm} Clark equatorial of the Washburn Observatory) an opaque screen in which are cut two narrow rectangular apertures of equal dimensions and with their homologous sides parallel. When light from a bright star is transmitted through these apertures there is produced in the focal plane of the objective a central image of the star and upon opposite sides of this a series of fringes of rapidly diminishing brightness which soon merge into each other and, in the case of very bright stars, become a faint and narrow brush of light streaming away from the central image parallel to the line joining the centers of the apertures. For stars of moderate brightness, third to sixth magnitude, a certain number of the fringes are indistinguishable in appearance from faint stars and the central portion of the interference pattern resembles a multiple star of symmetrical arrangement, the relative position of whose several parts may be determined with a micrometer with all the precision of similar double star observations. The theory of these fringes is contained in the text books of optics, and reference may also be made to a peculiarly succinct and elegant treatment of the subject by M. Hamy (*Bull. Astron.*, **10**, 489).

In general the intensity of the light at any point of the interference pattern is represented by a definite integral whose limits are so determined as to include the entire angular extent of the source of light, but in the case of a fixed star this area may be replaced by a single element of the integral, from which all of the light is supposed to proceed, and if we put (see the article of M. Hamy above cited)

a = the linear width of each slit in the screen.
na = the distance between the axes of the slits.
λ = the wave-length of the light in question.
C = a constant.
θ = the angular distance from the central image of any point on the axis of the interference pattern

we shall have for the intensity of the illumination at any point on the axis of the pattern by a little transformation of M. Hamy's equations

$$I = \left[C \frac{\sin \alpha}{\alpha} \cos n\alpha \right]^2 ,$$

where α is an auxiliary quantity defined by the relation

$$\alpha = \pi \frac{a}{\lambda} \theta .$$

In the case of an ordinary star whose light is not monochromatic the total brightness must be found by multiplying this value of I by $d\alpha$ and integrating between limits corresponding to the extreme values of λ in the visible spectrum. This process is, however, quite unnecessary for those parts of the pattern in which the fringes are indistinguishable in appearance from faint stars, *e. g.*, of the tenth magnitude, since the total amount of light here present is so small that only the brightest part of the spectrum is visible, and the limits of integration are brought so close together that the single element of the integral, I, may be taken as proportional to the brightness and as determining, through α and θ, the value of λ corresponding to the point of maximum brightness in the spectrum, *i. e.*, the effective wave-length, as shown below.

It is evident that I is a periodic function of α and the points of maximum illumination may be found by differentiating the function with respect to α. We thus obtain as the criterion for the positions of the fringes the transcendental equation

$$\alpha [1 - n \tan \alpha \tan n\alpha] = \tan \alpha ,$$

which may be solved by trial when n is given. For the apparatus which I have employed

$$n = 2, \qquad a = .27^{mm}.0, \qquad h = 373^{mm}.5,$$

where h represents the length of the slits. The first few values of α corresponding to $n = 2$ are

α_0	α_1	α_3	α_5	α_7
$\pm 0^\circ.0$	$\pm 82^\circ.2$	$\pm 265^\circ.9$	$\pm 447^\circ.5$	$\pm 628^\circ.3$

It will be noted that, with exception of the first number, these values are approximately the odd multiples of $\frac{\pi}{2}$ and the distinguishing subscripts are assigned with reference to this relation.

Since α is a function of the wave-length of light, it appears

that the maximum illumination must occur at different points for different values of λ, and the fringes therefore be iris bordered, but this appearance is perceptible to the eye only in the case of the central fringes of a very bright star, since the divisor a^2 which appears in the expression for I corresponds to so rapid a diminution of the brilliancy of successive fringes that only those rays which most strongly excite the retina are visible, the outer fringes being reduced to minute stellar points whose distance from the central image, θ, or from each other, 2θ, may be measured with the micrometer and employed for a determination of the corresponding effective wave-length from the equation

$$\lambda = \pi a \left(\frac{\theta}{a}\right)_i ,$$

where i denotes the order of the fringe.

In the determination of wave-lengths, I have uniformly measured the distance, 2θ, between corresponding fringes on opposite sides of the central image, using the most remote fringes which could be seen with sufficient precision to permit of accurate settings of the micrometer threads.

I have observed the common precautions which the experience of double star observers has indicated as essential to the accurate measurement of distances, and in order to bring into the most favorable position the objects whose distance was to be measured, the screen was always placed in front of the objective with the axis of the slits parallel to the declination axis of the telescope.

In order that the observations should extend over a considerable range of stellar colors, a part of the stars to be observed were selected from Krüger's *Catalog der farbigen Sterne*, and the color numbers, rounded off to the nearest unit, there assigned to the several stars are given below. In some cases it has been necessary to translate a literal symbol into a numerical one. Another portion of the observing programme has been selected from the *Draper Catalogue*, viz., bright stars whose spectrum is there designated by the letter *A*. The color number 0 is assumed to correspond to these stars. Two faint companions

to brighter stars which appear to me distinctly green or bluish green are indicated by the symbol *G*, since Krüger's numerical symbols do not extend to these colors.

Since the present series of observations is purely experimental, I have not sought to multiply observations of the same star, but have for the most part confined myself to two independent determinations of wave-length for each star of the list. For a few stars, however, a larger number of determinations has been made, and I give below the separate results in every case where more than four observations of a single star are available. All observations made on the first fringe are rejected, since the small value of a for that fringe gives very large effect to the accidental errors of observation. The wave-lengths are expressed in millionths of a millimeter, and the number of the fringe from which each determination was made is given.

Vega		Altair		μ Cephei	
572	3	558	3	576	3
560	5	546	3	565	3
559	5	557	5	570	3
554	5	561	5	575	5
564	5	558	7	583	3
549	7	555	7		
570	7				

Vega and Altair are typical white stars, while μ Cephei, the garnet star of W. Herschel, is called the reddest lucid star in the northern hemisphere. The great brilliancy of Vega gives to its fringes a sensible width, which in some measure diminishes the accuracy of the observing.

The differences in the individual determinations above shown are not wholly accidental, and a comparison of all of the data shows the following systematic differences between results derived from different fringes:

Fringes	$\Delta\lambda$	p. e.
7 − 5	+ 1$^{\mu\mu}$.0	± 0.8
5 − 3	+ 5 .5	± 1.1
3 − 1	− 6 .5	. . . .

These differences are sufficiently explained by the supposition that the measured distance 2θ between the fringes designated by the subscript 3 requires a systematic correction of $+0''.13$. This correction agrees in sign and very approximately in magnitude with systematic corrections to my micrometer measurements derived in connection with observations of double stars, and regarding it as well established, I assume the corresponding correction of $+6^{\mu\mu}.0$ to all wave-lengths derived from fringe 3, and treat the results from the other fringes as free from systematic error.

After the application of this correction, I find from 124 residuals furnished by 51 stars a probable error $r_1 = \pm 3^{\mu\mu}.4$ for a single determination of λ. The measure of precision thus indicated, while very small by comparison with standard determinations of the wave-length of the Fraunhofer lines, is sufficient to furnish some conclusions respecting the influence of color upon effective wave-length, and the data from which these conclusions are to be drawn is set forth in the following table, whose first four columns seem to require no explanation further than the statement that the letters, *A*, *B*, placed after the name of a star denote, respectively, the brighter and fainter components of a double star. In the last three columns λ_0 denotes the mean value of the effective wave-length, n, the number of observations included in this mean, and *D. C.* the type of spectrum assigned the star in the *Draper Catalogue*. The character ? appended to these symbols is taken from the *D. C.*, and denotes that the results obtained from different plates were discordant after a second examination. The same symbol in the fourth column is assigned by myself and indicates an uncertain identification of the color.

Star	R. A.	Dec.	Color	λ_e	n	D. C.
α Lyrae	$18^h\ 33^m$	$38°\ 7$	o	562	7	A
α Aquilae	19 45	8 .6	o	559	6	A
α Urs. Min.	1 19	88 .7	o	562	2	A
α Androm.	0 3	28 .5	o	559	2	A
o Androm.	22 57	41 .8	o	565	2	A
σ Androm.	0 13	36 .2	o	568	2	A
α Pegasi	23 0	14 .7	o	560	2	A
γ Pegasi	0 8	14 .6	o	568	1	A
η Cassiop.	0 43	57 .2	o?	570	2	F
ψ Cygni	19 54	52 .0	o?	559	1	A
θ Cygni	19 32	49 .9	o?	563	1	F?
β Lyrae	18 46	33 .2	1	563	4	G
γ Delphini, A	20 42	15 .8	1	573	4	K?
γ Delphini, B	20 42	15 .8	1?	573	1	...
ι Aquilae	19 32	— 1 .5	1	569	2	A
35 Arietis	2 38	27 .3	1	565	2	A
υ Androm.	1 31	40 .9	1	564	2	F
α Aquarii	22 1	— 0 .8	1?	576	2	K?
Androm.	0 12	38 .1	2	562	2	A
δ Draco	19 12	67 .5	2	564	2	L?
ξ Pegasi	22 42	11 .7	2	576	4	F
ψ Aquarii	23 11	— 9 .6	2	575	2	H
Capricorni	21 17	— 17 .3	3	574	2	H?
5 Lacertae	22 10	39 .2	3	578	2	I
β Urs. Min.	14 51	74 .6	4	574	2	L?
λ Pegasi	22 42	23 .0	4	580	2	K (?)
35 Pegasi	22 23	4 .2	4	580	2	K
ϵ Pegasi	21 39	9 .4	4	564	2	K
ι Cephei	22 46	65 .7	4	580	2	I?
λ Androm.	23 33	45 .9	4	576	2	K
ζ Aurigae	4 56	40 .9	4	564	2	I?
ζ Cephei	22 7	57 .7	5	574	2	K?
1 Lacertae	22 12	37 .2	5	578	3	I?
3 Lacertae	22 20	51 .7	5	577	2	I
11 Lacertae	22 36	43 .8	5	574	2	H
β Androm.	1 4	35 .1	5	570	2	K?
γ Androm., A	1 58	41 .8	5	568	2	K
γ Androm., B	1 58	41 .8	G	564	1	...
γ Aquilae	19 42	10 .4	6	573	2	K
τ Aquarii	22 44	— 14 .1	6	581	2	M?
λ Aquarii	22 47	— 8 .1	6	579	4	M?
3 Aquarii	20 42	— 5 .4	6	570	2	...
α^2 Capricorni	20 12	— 12 .8	6	572	2	H?
30 Piscium	23 57	— 6 .6	6	580	2	H
δ Sagittae	19 43	18 .3	6	573	2	M?
γ Sagittae	19 54	19 .2	7	575	2	K
β Pegasi	22 59	27 .5	7	572	2	M?
ψ Pegasi	23 53	24 .6	7	580	2	H
β Cygni, A	19 26	27 .7	7	571	3	Q?
β Cygni, B	19 26	27 .7	G	574	2	A?
5 Lacertae	22 25	47 .2	7	577	2	H?
α Orionis	5 49	7 .4	7	570	2	M?
R Lyrae	18 52	43 .8	7	570	3	M?
α Tauri	4 30	16 .3	7	570	4	K?
μ Cephei	21 40	58 .3	8	577	5	M?

Even a casual inspection of these values of λ_0 will suffice to show a progressive increase in the numbers, but this sequence is best brought out by taking mean values for groups of stars selected with reference either to the color number or to the type of spectrum. Thus, with respect to color we have

Color No.	Stars	λ_0
0	11	$563^{\mu\mu}.2$
1–2	11	569 .1
3–4	9	574 .4
5–6	14	573 .8
7–8	9	573 .6

With respect to the type of spectrum, the symbols of the *Draper Catalogue* being translated in accordance with the introduction to that volume, we have

Class	Stars	$\lambda_0^{\mu\mu}$
I	13	564.0
II	31	572.6
III	7	574.6

These tables agree in differentiating the white stars of the Sirian type from the yellow or solar stars by a much wider interval than separates the latter from the red stars with banded spectra. Indeed, the difference in the values of λ_0 coresponding to the last two classes but little exceeds the probable error of the tabular numbers. In view of the limited number of stars observed it will be best to restrict conclusions from the preceding data to the statement that the effective wave-length of the light of stars which are distinctly colored is approximately $9^{\mu\mu}$ greater than that of white stars; and that stars of the deepest red color do not sensibly differ in effective wave-length from those of a yellow hue.

If we adopt Kayser and Runge's value for the atmospheric dispersion of light (*Astronomy and Astrophysics*, No. 115) it may readily be shown that at a zenith distance of 45° the difference of $9^{\mu\mu}$ in effective wave-length corresponds to a difference of about $0''.03$ in the refraction, and this may obviously be neglected in all cases save those in which the utmost possible precision is required.

The observations above set forth are to be considered as a first attempt, with homemade apparatus, at applying interference methods to the problem in hand. The screen was cut from a piece of pasteboard, and the adopted average width of the slits, $a = 27^{mm}.0$, is uncertain to the extent of $0^{mm}.1$ or $0^{mm}.2$ corresponding to something less than 1 per cent. in the absolute values of the wave-lengths. The relative values are, however, free from this source of error, since the same screen was used in all of the observations.

A serious limitation upon the more extended use of the method is the difficulty attending its application to faint stars. With the apparatus which I have employed the sixth or possibly the seventh magnitude constitutes the limit at which the third fringe is bright enough to be satisfactorily measured, and if the observations are to be extended below this limit the first fringe must be used and a large part of the precision of the results sacrificed.

WASHBURN OBSERVATORY,
November 24, 1896.

REMARKS ON THE ARTICLES OF MR. E. J. WILCZYNSKI IN THIS JOURNAL VOL. IV. NO. 2.

By PAUL HARZER.

IN the first of these articles my mathematical treatment of the solar rotation in *A. N.* 3026 is accused of lacking vigor. On the contrary I shall show that the deductions of Mr. Wilczynski are quite erroneous.

The principal error is the conclusion drawn from equations (6), that ω^2 does not depend upon c and depends only upon $\sqrt{a^2+b^2}$. This conclusion is tenable only in the case of the symbol

$$dP = \frac{dp}{\rho}$$

being really integrable. But in general from equations (6) or, more clearly written, from

$$\frac{dV}{da} - \frac{1}{\rho}\frac{dp}{da} = -\omega^2 a \qquad \frac{dV}{db} - \frac{1}{\rho}\frac{dp}{db} = -\omega^2 b \qquad \frac{dV}{dc} - \frac{1}{\rho}\frac{dp}{dc} = 0$$

we deduce the relations

$$\frac{d^2V}{da\,db} - \frac{1}{\rho}\frac{d^2p}{da\,db} = -a\frac{d\omega^2}{db} - \frac{1}{\rho^2}\frac{d\rho}{db}\frac{dp}{da} = -b\frac{d\omega^2}{da} - \frac{1}{\rho^2}\frac{d\rho}{da}\frac{dp}{db}$$

$$\frac{d^2V}{da\,dc} - \frac{1}{\rho}\frac{d^2p}{da\,dc} = -a\frac{d\omega^2}{dc} - \frac{1}{\rho^2}\frac{d\rho}{dc}\frac{dp}{da} = -\frac{1}{\rho^2}\frac{d\rho}{da}\frac{dp}{dc}$$

$$\frac{d^2V}{db\,dc} - \frac{1}{\rho}\frac{d^2p}{db\,dc} = -b\frac{d\omega^2}{dc} - \frac{1}{\rho^2}\frac{d\rho}{dc}\frac{dp}{db} = -\frac{1}{\rho^2}\frac{d\rho}{db}\frac{dp}{dc}$$

and hence

$$a\frac{d\omega^2}{db} - b\frac{d\omega^2}{da} = \frac{1}{\rho^2}\left(\frac{d\rho}{da}\frac{dp}{db} - \frac{d\rho}{db}\frac{dp}{da}\right)$$

$$\frac{d\omega^2}{dc} = \frac{1}{a\rho^2}\left(\frac{d\rho}{da}\frac{dp}{dc} - \frac{d\rho}{dc}\frac{dp}{da}\right) = \frac{1}{b\rho^2}\left(\frac{d\rho}{db}\frac{dp}{dc} - \frac{d\rho}{dc}\frac{dp}{db}\right)$$

Therefore in general neither $a\frac{d\omega^2}{db} - b\frac{d\omega^2}{da}$ nor $\frac{d\omega^2}{dc}$ are vanishing.

Another error involves the formulæ (5) as they contradict the supposition that a, b, c represent the values of x, y, z, for $t = 0$. The correct formulæ are:

$x = a \cos \omega t - b \sin \omega t \qquad y = a \sin \omega t + b \cos \omega t \qquad z = c$

The equations (6) remain unaltered by introducing these formulæ into equations (1).

By means of the erroneous formulæ (5) Mr. Wilczynski concludes that all conditions are satisfied, it being easy to prove that D vanishes. He is here overlooking the fact that a vanishing value of D is physically impossible, D representing the relation of the elementary volumes for the times $t = t$ and $t = 0$. The correct formulæ for x, y, z, giving

$$D = \Delta + \left(a \frac{d\omega}{db} - b \frac{d\omega}{da} \right) t,$$

the condition of continuity requires the expression

$$\rho \left(\Delta + \left(a \frac{d\omega}{db} - b \frac{d\omega}{da} \right) t \right) = \rho \left(\Delta + \frac{1}{2\rho^2 \omega} \left(\frac{d\rho}{da} \frac{dp}{db} - \frac{d\rho}{db} \frac{dp}{da} \right) t \right)$$

to be invariable for a moving elementary mass.

This condition is fulfilled only in consequence of certain suppositions regarding the constitution of the revolving mass, for instance the supposition that the density and the pressure are the same at all similarly situated points of all plane sections across the axis of rotation. Then ρ does not change for a moving elementary mass and ρ, p and ω^2 depend only upon $1/\sqrt{a^2 + b^2}$ and $1/\sqrt{a^2 + b^2 + c^2}$; but even in this special case the value of $\frac{d\omega^2}{dc}$ does not vanish.

I think that the vanishing value of $\frac{d\omega^2}{dc}$ must have led Mr. Wilczynski to the objection against my treatment of the problem. But the error is his, not mine.

In view of these facts Mr. Wilczynski's considerations cannot be maintained; for if they are legitimate they ought to be limited to cases of integrable values of $\frac{dp}{\rho}$, for instance to incompressible fluids or to gases at *constant* temperature, *i. e.*, to cases the existence of which we have no reason to assume anywhere in nature.

GOTHA, October 10, 1896.

RESEARCHES ON THE ARC-SPECTRA OF THE METALS. III. COBALT AND NICKEL. III.[1]

By B. HASSELBERG.

SPECTRUM OF NICKEL.

Nickel λ	R.	i Ni	i ⊙	REMARKS	Liveing and Dewar
3458.59		4	4	Very diffuse. Reversed.	58.45
61.78		4	4	Very diffuse. Reversed.	61.66
62.95		1	2	Ni ?	
67.63		2.3	2	Sharp.	67.35
69.64		2.3	3	Sharp.	69.45
72.68		3.4	3	Diffuse. Reversed.	72.45
78.48		1	1.2		
79.43		1	1		
80.36		1	1		
86.04		2.3	2		85.75
——	3486.04				
93.10		4.5	4	Very diffuse. Reversed.	92.85
96.50		1	1		
3501.00		3	2.3		00.55
02.76		2	2		
07.85		2	2	Sharp.	07.86
10.47		4	4	Diffuse. Reversed.	10.26
——	3510.99				
14.06		2.3	2.3		
15.17		4.5	4	Very diffuse. Reversed.	14.96
16.35		2	1.2		
18.80		2	2		18.56
19.90		3	2.3		19.66
23.19		1.2	1.2		
24.65		5	4	Very diffuse. Reversed.	24 46
28.13		2.3	2		
29.03		1.2	1		
29.76		1	1		
30.73		1.2	1.2		30.47
33.89		1	1	Diffuse.	
——	3540.27				
48.34		2.3	2.3	Also Mn.	48.07
51.66		2.3	2		51.37
53.63		2	2		53.37
——	3558.67				
60.08		1	1		
61.91		2	1.2	Very sharp.	61.67
66.50		4.5	4	Very diffuse. Reversed.	66.27

[1] Continued from p. 366.

Nickel λ	R.	i Ni	i ⊙	Remarks	Liveing and Dewar
3571.99		3.4	3	Diffuse. Reversed.	71.78
77.37		1	1		
——	3583.48				
88.08		2.3	2.3	Very sharp.	
97.84		3.4	3.4	Diffuse.	97.58
3602.41		2.3	2		
——	3605.63				
07.02		1	1		
09.44		2.3	2		
10.60		4	3	Reversed.	10.38
11.58		1	1		
12.86		3.4	2.3		12.68
19.52		5	5	Very diffuse. Reversed.	19.38
24.87		3	2.3	Very sharp. ⊙ line double { 24.87 Ni. .97 Fe, Ti. }	24.68
30.04		1.2	1.2		
35.10		2	2	Very sharp. ⊙ line a close double.	35.49
——	3635.62				
41.78		1.2	1.2		
42.58		1	—	{ Ni ?	
44.13		1	—	}	
——	3658.69				
62.10		2	1.2	Very sharp.	
64.24		3	2.3	Very sharp. ⊙ double { 64.16 Fe. .24 Ni.	63.99
68.35		1	1.2		
69.38		2	2	Very sharp. ⊙ double { 69.30 Fe. .37 Ni.	
70.57		2.3	2.3	Very sharp.	70.29
74.28		3.4	2	Very sharp. ⊙ double { 74.18 Fe. .28 Ni.	73.99
83.65		1	?		
——	3684.26				
88.58		2.3	2.3	Very sharp.	88.19
94.10		2	2.3	⊙ line a close double { 94.10 Ni. .20 Fe.	
97.04		1	1		
3713.49		1	1		
13 87		1	1		
15.61		1.2	2		
——	3716.58				
22.63		3	4	Ni line on the red edge of the ⊙ line 22.70 Fe, Ti.	
24.95		1.2	1.2		24.80
29.05		1	2		
30.88		1.2	2		
36.94		3.4	3.4	Very sharp.	36.70
39.36		2.3	2	⊙ line triple { 39.26 Fe. 36 Ni. .46 Fe.	
39.89		1	1.2		
——	3743.50				

Nickel λ	R.	i Ni	i ⊙	Remarks	Liveing and Dewar
3744.68		2.3	2	Very sharp.	
49.15		2	2.3	Very sharp. ⊙ line probably double.	
62.76		2	1		
69.58		1	1.2		69.50
72.70		2.3	2	Sharp.	
——	3774.48				
75.71		4.5	2.3		75.62
78.22		1.2	1.2		
83.67*		4	2.3		83.62
92.48		2.3	2	Very sharp.	
93.75		3	2	Very sharp.	
——	3805.49				
3807.30		4	3		07.22
11.46		1	1.2	⊙ line a close double { 11.46 Ni. .56 Ti.	
29.49		2.3	—		
31.82		3	3		
32.44		2.3	4		32.32
33.02		2	1.2		
——	3836.23				
44.40		1.2	2	Very diffuse.	
44.71		1.2	1		
58.40		4.5	3	Reversed.	58.42
63.21		2.3	1.2		
——	3864 44				
71.73		1.2	1		
——	3886.43				
89.80		2.3	2	Very sharp.	
3905.67		1.2	4	Probably a foreign line.	
09.10		1.2	1.2	Very diffuse.	
12.44		1.2	1.2	Very diffuse.	
13.12		2	1.2		
14.65		1	?		
——	3916.87				
44.25		3.4	—	Very diffuse.	
——	3954.00				
54.61		1.2	—	Very diffuse.	
70.65		2	—	Very diffuse.	
72.31		2.3	2		
73.70		4	2.3	⊙ line a close double { 73.70 Ni. .81 Fe.	
74.83		2	—	Very diffuse.	
——	3977.89				
84.18		2	—	Very diffuse.	
94.13		2	—	Very diffuse.	
95.45		3.4	2.3		
——	4003.92				
4006.30		2	1.2		
10.14		1.2	?		
17.65		2	—	Very diffuse.	
19.20		1.2	1.2		
22.20		1	—		

Nickel λ	R.	i Ni	i ⊙	Remarks	Thalén
4025.26		1.2	1.2		
——	4034.64				
46.91		1	—		
57.45		1	—		
——	4062.60				
64.55		2	—		
69.39		1	—		
73.08		1	—		
75.05		1.2	—	Sharp.	
75.75		1.2	—	Diffuse.	
86.30		1	1		
——	4088.72				
4104.37		1	—		
16.14		2	1		
21.48		3	3	Sharp. 21.41 Cr.	
——	4121.97				
23.96		1	—		
38.67		1	?		
42.34		1	1.2		
42.47		2	1.2		
43.12		1	1		
50.55		1.2	1.2	⊙ has 50.48 Fe.	
——	4157.95				
64.82		1	1	Sharp.	
67.16		1.2	—	Diffuse.	
84.65		1.2	—		
——	4185.06				
95.71		2.3	1.2	⊙ a close double { 95.71 Ni. .77 Fe.	
4200.61		2	1.2	Sharp.	
01.88		2.3	1.2	Sharp.	
02.33		1	—		
21.87		1	—		
——	4231.15				
31.23		2	—		
36.55		1.2	—		
52.25		1	1		
——	4254.50				
84.83		2.3	1.2		
88.16		3.4	2	⊙ double { 88.05 .15	
——	4293.25				
96.06		3	1		
97.15		1	2		
98.68		1.2	1		
98.94		1	1.2		
4307.40		1.2	1.2		
——	4308.03				
25.49		1.2	1.2	Diffuse.	
25.75		2.3	1.2	Sharp.	
30.85		2.3	1.2	Intensity of the Ni line variable.	
31.78		3	—		

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
——	4343.39				
4356.07		2	1.2	Diffuse.	
59.73		3	2	Sharp. ⊙ line the middle line of a Close triplet. Cr has 59.78, Ba 59.80.	
68.45		2	1		
70.21		1.2	1	Diffuse. ⊙ perhaps double.	
——	4376.10				
83.05		1	—		
84.68		2.3	1.2		
86.62		1.2	?	Diffuse.	
90.00		2	1		
90.47		1.2	?	Diffuse.	
98.78		1	1		
99.75		2	1		
4401.02		2	1.2		
01.70		4.5	2	⊙ line double { 01.60 .70 Ni }	
——	4407.85				
10.70		2.3	2	Diffuse.	
23.24		1.2	1		
——	4435.13				
37.17		2.3	2		
37.75		2	—		
41.64		1	—		
42.61		2	—		
50.29		1	—		
50.44		1	—		
——	4456.05				
59.21		4.5	2	⊙ line double { 59.20 Ni .30 Fe }, (K.—R:59.30)	
62.59		4	2		
63.57		2	1.2		
66.54		2	1		
70.61		4	2.3		
81.30		1	1.2	Diffuse.	
90.71		2	1	Diffuse.	
——	4494.17				
4506.53		1	—		
——	4508.46				
13.20		2	1		
20.20		2.3	1	Very sharp.	
——	4531.40				
47.14		2	2	⊙ has { 47.15 Ni .25 Fe } (K.—R:47.20)	
47.44		2.3	1.2		
51.45		2	1		
53.37		1.2	1		
——	4554.21				
60.10		2	1		
67.59		1	—		
80.77		1.2	1.2		
——	4588.38				

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
4592.69		3.4	2.3	⊙ has { 92.70 Ni / .80 Fe } (K.—R:92.81)	
95.07		2	1.2		
96.11		2	—	Diffuse.	
4600.51		3	2		
05.15		4	2.3		
06.37		2.3	1.2		
14.85		1	1		
18.22		1.2	1	⊙ line double { 18.15 / .22 Ni	
——	4611.45				
47.47		1.2	1		
48.82		3	2.3		
55.85		1+	1		47.88
67.16		1.2	1.2		
67.96		2	1.2		
——	4668.30				
75.80		1	1		
86.39		2.3	2	Sharp. Cr. has 86.38; lines probably divided	
——	4686.39				
4701.52		1	1.2		
01.72		2	1.2		
——	4703.18				
03.96		2.3	2	Diffuse.	
12.24		1	1		
14.59		4.5	3		14.54
15.93		3	2		
——	4727.63				
28.06		1	1		
29.50		1	1		
32.00		2	1.2		
32.66		2	1.2		
52.30		1.2	1.2	Coincides with a Cr line. The other strong lines of Cr in this neighborhood are missing.	
52.58		2	1.2		
——	4754.23				
54.95		1.2	1.2		
56.70		3	2		55.84
62.78		1.2	1.2		
64.07		2	2		
73.55		1	1		
——	(4780.10)			(1)	
86.42		1	1.2		
86.66		3	2.3		86.64
92.98		1	1.2		
——	4805.25				
4807.17		2	2		
09.05		1	1		
12.15		1	1		
14.77		1	1		
17.97		1	1.2		
21.29		1	1.2		

[1] The lines λ 4780.10, 4950.25, and 5227.40 are taken from Rowland's map of the solar spectrum.

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
——	4824.33				
4829.18		3	2.3		29.30
31.30		2.3	2.3		31.10
22.86		1.2	2		
38.80		2	2		
43.27		1	1.2		
52.70		1.2	2	Diffuse.	
55.57		3	2.3		55.60
57.57		1.2	2		
——	4859.93				
64.11		1.2	1	Diffuse.	
64.46		1	1.2	Diffuse.	
66.42		3.4	2		66.20
70.97		2	2	Cr has a strong line at 70.96; divided from Ni, and λ Cr < λ Ni	
73.60		2	2		73.80
74.95		1	1		
87.16		1.2	2		
——	4890.94				
4904.56		3.4	2.3		04.70
12.22		1.2	1.2	Diffuse.	
14.15		2	1.2	Diffuse.	
18.53		2.3	2	Sharp.	18.40
18.86		1	1.2		
25.74		1.2	1.2		
——	4934.25				
36.02		2	2	Sharp.	35.90
37.51		2	2	Very diffuse.	
45.63		1.2	2	Diffuse.	
——	(4950.25)				
46.20		1	1		
53.34		1.2	1.2		
71.54		1.2	2		
——	4973.27				
76.54		1	1.2		
80.36		3.4	2.3		80.40
——	4981.92				
84.30		3.4	2.3		84.10
97.04		1	1.2	Diffuse.	
98.42		2	2		
5000.48		2.3	2	Diffuse. ⊙ line double.	
03.92		1	1.2		
10.22		1	1		
11.11		1.2	1.2	Diffuse.	
12.62		2	2	Sharp.	
17.75		3.4	2.3		17.45
18.50		2	2	Very diffuse.	
——	5020.21				
35.55		5	2.3		35.56
38.80		2	2		
42.35		2.3	2	Diffuse.	
49.01		2.3	2	Diffuse. Cr has 48.96, distinctly divided.	

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
5051.74		1	1.2	Very diffuse, ⊙ line double { 51.75 .85	
58.22		1	1		
——	5060.25				
80.16		1.2	1.2		
80.70		5	2.3		80.70
81.30		5	2.3	Diffuse.	81.56
82.55		2.3	2	Diffuse.	
——	5083 53				
84.27		4	2.3	Diffuse.	
88.74		1	1.2		
89.13		1	1.2		
94.61		1	1.2		
97.06		2	2	Diffuse.	
99.50		2.3	2.3	Sharp.	99.46
5100.13		3.4	2.3	Diffuse.	00.66
03.13		2	1.2		
——	5110.57				
15.55		4	2.3	Very sharp.	16.00
21.74		1.2	?		
25.39		2.3	2.3	⊙ line a close double.	
29.52		3	2.3		
30.55		1	1		
31.94		1.2	1.2	Diffuse.	
37.23		4	2.3	Very sharp.	37.91
——	5141.92				
42.96		3.4	2	Diffuse.	43.11
46.64		4	2	Diffuse.	46.81
53.43		2	2		
55.34		2	2	Diffuse.	
55.92		3.4	2.3	Diffuse.	56.21
58.20		1	1		
——	5167.57				
68.83		2.3	2		69.41
76.73		2	2		76.71
84.78		1.2	1.2		
86.80		1	1		
——	5188.95				
92.70		1	?		
97.40		1	1		
——	5198.89				
5216.72		1	1		
20.51		1	1		
——	(5227.40)				
68.59		1	1		
——	5270.49				
5371.64		2.3	2		
——	5379.77				
88.71		1	1		
92.68		1	1		
——	5397.34				
5411.50		2	1.2	Sharp.	
——	5415.42				

Nickel λ	R.	i Co	i ⊙	Remarks.	Thalén
5424.85		2	1.2		
——	5434.74				
36.10		2.3	1.2	Very sharp.	
62.71		2	1.2		
——	5466.61				
68.42		1	1		
77.13		5	3		77.20
95.20		1.2	1	Sharp.	
——	5497.73				
5504.50		1.2	?		
10.28		2.3	1.2	Sharp.	
——	5513.21				
53.97		2	1.2	Sharp.	
——	5555.11				
78.98		2.3	1.2		
——	5582.19				
88.12		2.3	1.2	Sharp.	
89.63		2	1	Diffuse.	
92.44		3.4	2	Sharp. ⊙ line a close double. Coincident with red component.	
94.00		3	1.2		
5600.29		2	1.2		
15.00		3	1.2	Sharp.	
——	5615.88				
25.56		3	1.2		
28.62		1.2	1		
37.32		2	1.2		
39.02		1.2	—		
42.08		1.2	1		
43.31		1.2	1	Diffuse.	
——	5645.83				
49.90		2.3	1.2		
64.28		2.3	1.2		
70.22		2	1		
——	5675.65				
82.44		3.4	1.2	Diffuse.	
95.22		3	1.2	Diffuse.	
——	5701.77				
5709.80		3.4	2		
12.10		3	2		
15.31		3	2	Also a Ti line.	
——	5715.31				
48.57		1.2	1.2		
54.86		3	2.3		
61.10		2.3	1.2		
——	5763.22				
96.35		1	1		
5805.45		2	2		
——	5806.95				
47.26		1	1.2		
58.03		2	2		57.72
——	5859.81				
93.13		2.3	2		93.22
——	5896.15				

As the last column of this catalogue shows, the number of lines which Thalén observed in the spectrum of the induction spark is quite small; still it is sufficiently large to afford a basis for estimating the accuracy of his measurements. If the differences between our wave-length values are formed it will be found that they have a wholly accidental character, and that the probable error[1] of one of Thalén's wave-lengths is:

From observations of the cobalt spectrum, $s_1 = \pm 0.32$ tenth-meters.
From observations of the nickel spectrum, $s_{11} = \pm 0.24$ tenth-meters.

Among the lines of cobalt there is one, λ 5359.4, for which the difference *H-Th* reaches the abnormally high value of -1.34 tenth-meters. If this exceptional case is excluded, then $s_1 = \pm 0.26$ tenth-meters, a value which is in complete agreement with the probable error of the observations of the nickel spectrum, and with that of the observations of titanium already discussed. It would be difficult to find any observations made at that time which are comparable, with respect to accuracy, to the observations of Thalén.

The differences between my wave-lengths and those of Liveing and Dewar, in the ultra-violet part of the spectrum measured by both of us, run somewhat differently. They are positive almost throughout, corresponding to a systematic deviation which is in the mean

$$H - LD = +0.12 \text{ tenth-meters, for cobalt,}$$
$$= +0.19 \text{ tenth-meters, for nickel.}$$

Since, however the wave-lengths of Liveing and Dewar are referred to Rowland's earlier wave-length of the *D* lines, for which Bell subsequently found the correction + 0.06 tenth-meters, it is necessary, in order to reduce the above differences to the wave-length system of my observations, to apply the correction − 0.06. Thus they finally become

$$H - LD = +0.06 \text{ tenth-meters, for cobalt,}$$
$$= +0.13 \text{ tenth-meters, for nickel;}$$

[1] The probable error of my own observations is included in these values; but since this hardly exceeds ± 0.02 tenth-meters, the above figures also give the probable error of Thalén's measures with reference to Rowland's scale.

or, taking the mean,

$$H - LD = +0.10 \text{ tenth-meters.}$$

This agreement is certainly to be regarded as a very satisfactory one.

The existence of cobalt and nickel in the Sun's atmosphere is a fact which has long been established. It is at once apparent on comparing the third and fourth columns of the table. If we arrange the lines in groups, according to their intensity, we obtain the following table showing the number of coincidences and non-coincidences for each group:

COBALT.

i	Coinc.	Non-Coinc.
1–1.2	73	150
2–2.3	143	106
3–3.4	76	17
4–4.5	29	2
5– .6	5	0

NICKEL.

i	Coinc.	Non-Coinc.
1–1.2	118	34
2–2.3	114	11
3–3.4	45	2
4–4.5	22	0
5– .6	6	0

It will be seen that the lines of nickel, especially in the weaker classes, are represented in the solar spectrum with considerably greater completeness than those of cobalt. Thus, while 86.5 per cent. of all the observed nickel lines are represented by solar lines, the percentage for cobalt is only 54.3. If we exclude the weakest class of lines, on the ground that it is more likely than others to contain foreign lines due to impurities, the percentages become respectively 93 and 66, and the significant difference between the two metals in this respect therefore still remains. This seems to indicate that there is more

nickel than cobalt in the solar atmosphere. In order to test this supposition I have arranged the coincident solar lines in groups, according to their estimated intensities, giving for each group the number of coincidences and the percentage which it forms of the total number of coincidences.

$i_\odot$	Co	Ni
1	120 = 37 p.c.	70 = 23 p.c.
1.2	74 = 22.5 "	96 = 31.5 "
2	84 = 25.6 "	77 = 25.2 "
2.3	31 = 9.4 "	40 = 13 1 "
3	15 = 4.6 "	9 = 3 "
> 3	2 = 0.6 "	13 = 4.2 "

This table shows that of the coincident solar lines the weakest are represented more numerously by cobalt than by nickel, while for the stronger lines just the opposite is true. The assumption of a more intense absorption by nickel than by cobalt seems, therefore, to have some foundation in this fact, and since, on account of the approximate equality of their atomic weights, these two metals must exist in the Sun at the same temperature-level, the stronger absorption on the part of the nickel vapor would represen a greater quantity of that substance.

Minor Contributions and Notes.

BENJAMIN APTHORP GOULD.

Benjamin Apthorp Gould was born in Boston, September 27, 1824. After his course in Harvard College, where he graduated with distinction in 1844, he went to Europe and studied under Gauss, Encke, Struve, Peters, Hansen and Argelander. As Dr. Chandler has recently pointed out,[1] the influence which he exercised from that time forward contributed in a marked degree to the building up of American astronomy. In 1852 he was placed in charge of the longitude determinations of the Coast Survey, where he remained until 1867. While engaged in this work he found time to organize the Dudley Observatory at Albany, and from 1855 to 1859 he not only directed this institution, but carried it on at his private expense. In the ten years that followed he published much valuable work, including a discussion of the places and proper motions of circumpolar stars, since used as standards in the Coast Survey and, after revision in 1861, in the American Ephemeris; a reduction of D'Agelet's observations; reductions of the greater part of the observations made at the United States Naval Observatory since its establishment; reductions of the observations made by the expedition to Chili to determine the solar parallax; determination of the difference in longitude of European and American stations, made with the aid of the Atlantic cable; and the first reductions of astronomical photographs — Rutherfurd's negatives of the Pleiades. He also determined the right ascensions of all stars to the tenth magnitude within one degree of the pole with a transit instrument at his private observatory in Cambridge.

In 1865 he determined to extend his observations to the stars of the southern hemisphere. The expedition, organized at first with private assistance, finally resulted in the establishment of the Argentine National Observatory at Cordoba. The *Uranometria Argentina*, the zone observations of stars between 23° and 80° south declination, and the independent series of meridian circle observations for the

[1] In an appreciative paper on the life and work of Dr. Gould published in *Science*, December 18, 1896, from which many of the facts in the present notice are derived.

General Catalogue of 32,448 stars remain as lasting testimonials to the great work accomplished by Dr. Gould and his assistants. While at Cordoba he also secured some 1400 negatives of stellar clusters, the measurement and reduction of which he had practically completed at the time of his death.

The *Astronomical Journal* was established by Dr. Gould in 1849, and continued until 1861, when he was forced to suspend its publication. Fortunately for American astronomy it became possible to reëstablish the *Journal* in 1885, since when it has appeared regularly. Devoted exclusively to the publication of original investigations, the *Astronomical Journal* has performed a great service for science in the United States. It is satisfactory to know that it will be continued under the able management of Dr. S. C. Chandler, assisted by Professor Asaph Hall and Professor Lewis Boss.

Dr. Gould's numerous services to science received richly deserved recognition from many learned societies. His sudden death on November 26, 1896, the result of a fall at his home in Cambridge, will be widely mourned.

PHOTOGRAPHIC STUDIES OF THE MOON AT THE PARIS OBSERVATORY.

In a series of papers[1] published in the *Comptes Rendus* at various times during the last two years, MM. Loewy and Puiseux have given an account of the researches in lunar photography which they have carried on with the aid of the great equatorial coudé at Paris. Some of these papers are devoted principally to a description of the instrument and its adjustment, others to general remarks on the subject of lunar photography and the difficulties which must be overcome in order to realize the full capabilities of the apparatus at their command. An interesting point in this connection is the method which they use for getting rid of the motion of the image in declination, by choosing for exposure (with the aid of a previously prepared table), times when the Moon's motion in declination is neutralized by the change of parallax. The rate of the driving clock is controlled by the observer, without stopping the clock, by means of a sliding weight on the pendulum. In some places the authors give the conclusions to which they have been led, by a study of their photographs, as to the nature and prob-

[1] *C. R.* **119**, 130-135, 254-259, 1894; **121**, 6-12, 79-85, 1895; **122**, 967-973, 1896.

able origin of the characteristic features of the Moon's surface. The last published paper (*C. R.* **122**, 967–973, 1896) contains a somewhat more elaborate statement of these views, which differ in a number of important particulars from those of other observers. They resemble in many respects the views of Suess.[1]

This paper, when presented to the French Academy of Sciences, was accompanied by the first six sheets of a new photographic atlas, the scale of which is approximately 1 : 1,300,000. The corresponding lunar diameter is about $2^m.6$, and the scale, therefore, considerably exceeds that of Schmidt's map (2^m). Since the diameter of the image in the focus of the equatorial coudé is $0^m.18\pm$, the map represents an enlargement of 14 or 15 times. The enlargement is, however, not quite the same for all the plates, and a scale for each sheet would have added materially to the usefulness of the atlas.

The beautiful plates are heliogravures, prepared from enlargements on glass of the same size as the plates themselves ($0^m.48$ by $0^m.58$). The process is an expensive one, but it yields the best results. It is said that the grain of the negatives is finer than that of the plates used in America, and this is probably the case, as, judging by the relation between aperture and exposure, the plates seem to be slower. It may further be noted that the great focal length (18^m) of the equatorial coudé makes it specially suitable for the purposes of lunar photography, since with a large image the granulation of the negative is relatively less important than with a small one. The impressive size and fine definition of the unenlarged image obtained with the equatorial coudé are well shown by the exquisite heliogravure of the half Moon which forms the first plate of the atlas.[2]

We may now consider the explanation of the lunar markings which is proposed by the authors, and which forms part of the text accompanying the sheets. Suess remarks in the paper already referred to, that no selenographic theory can be established if it is not admitted that the forces which are revealed to us by their effects on the Earth equally exert their action on the Moon, and that the crusts of the two bodies are composed of similar materials. This reasonable hypothesis is accepted by Loewy and Puiseux as the basis of their own theory. So far as the character of the crust is concerned, the principle of Suess

[1] *Sitz. d. K. Akad. d. W. Wien*, February 1, 1895. English abstract in *Pub. A. S. P.*, No. 42, **7**, 139–148, 1895.

[2] See also the Annual Report of the Observatory of Paris for the year 1895.

need not be too rigidly applied. An assumption of identity in the materials of the crusts of the two bodies would oblige us to regard the density of the Moon as uniform, since the density of the volcanic rocks of the Earth is about the same as the mean density of the Moon. The lunar crust may be supposed to consist of materials considerably lighter than the ordinary volcanic rocks of the Earth without affecting the reasonableness of the assumption. In any case, the adoption of the hypothesis rules out all but a limited number of possible explanations of lunar formations.

The theory of Loewy and Puiseux is a modified form of the volcanic theory, and their attention is first given to an inquiry into the possibility of present or past eruptive action. The principal arguments opposed to the volcanic hypothesis may be reduced to the three following: (1) the annular formations on the Moon are entirely distinct, by reason of their form and size, from all known craters on the Earth; (2) every volcanic eruption is necessarily accompanied by an abundant disengagement of gas and aqueous vapor; (3) the Moon has neither a liquid surface nor an appreciable gaseous envelope, and its surface features have not been modified by the circulation of water. These objections are considered by the authors, their conclusion being that the conditions necessary for volcanic action probably existed in the past, if they do not exist now; moreover, they do not necessarily imply the existence of an atmosphere of considerable refractive power. The ordinary cause of explosions is the presence of water at great depths, and on the Moon the quantity of imprisoned vapors must have been greater than on the Earth, by reason of the more rapid cooling of the surface.

The authors believe, however, that there is some evidence of the present existence of a lunar atmosphere. Bessel's negative result has been generally accepted, yet modern observations have invariably shown that the Moon's diameter deduced from occultations of stars is smaller than that obtained from meridian transits. If they say, the values given by the two methods were definitive, the reality of a lunar atmosphere would be proved; but they do not mention the fa that there are reasons why the two methods should give results which differ in the manner actually observed,—reasons which have no connection with the possible existence of an atmosphere. Irradiation, diffraction, and imperfect definition arising from a variety of causes, all tend to increase the measured diameter of a bright object. This has been well

pointed out in a recent article by Mr. Campbell.[1] The difference in question, which is only from 1″ to 2″, is very probably thus fully accounted for. A more reliable test for the presence of an atmosphere would seem to be its effect on the outline of a planet during an occultation, or on the direction of the Sun's limb during an eclipse, and in such occurrences the evidence is generally negative, although there are some exceptions on record. The question, however, is not an important one for the argument, since it may be conceded that an atmosphere probably existed under past conditions, even if there is none at the present time. An examination of all the conditions leads the authors to conclude on *a priori* grounds, that the Moon was once specially well fitted for the display of eruptive phenomena.

In framing their hypothesis MM. Loewy and Puiseux have used all the well-known data, and to a considerable extent, it would appear, data which they have obtained from a study of their own photographs. The facts which they regard as most significant are as follows:

"(1) The mountainous regions of the Moon are traversed for great distances by straight grooves (rills), in the course of which numerous eruptive funnels have been formed. (2) These rills, which are distributed in several parallel systems, have frequently served to limit the contour of the craters, and have therefore contributed toward giving them their polygonal shape. (3) The great craters have a tendency to occur in groups of two, three or four, arranged in certain definite directions which agree with those of the rills in the same region; (4) it is not rare to find them surrounded by a ring of secondary craters; the top of the rampart is a favorite place for the subsequent formation of eruptive funnels and centers of explosion. (5) When several craters overlap, the smallest is ordinarily the deepest, and is the only one which has a complete wall and a central mountain. (6) In the deepest craters the interior is generally studded with numerous hills grouped around a central mountain. If the bottom is less deeply depressed it appears as a plain, from which the central peak alone emerges. If it is still higher the central peak disappears, and the whole interior has a uniform aspect entirely similar to that of the seas. A final category is formed by annular forms without an interior depression, where the rampart alone exists, often incomplete and half submerged. (7) The great plains known as seas have in general a circular form, and are not distinguished from the largest craters except by their size. It is only

[1] "A Determination of the Polar Diameter of Mars." *A. J.*, No. 354, **15**, 145.

in exceptional cases that their surface exhibits the cones, eruptive funnels and rills that are found in such great numbers on the high plateaus. Their outline is often marked by a fissure, either single or double, which forms the boundary between the plain and the mountainous regions. Veins, standing in slight relief, are seen traversing the surface of the plain, having, like the fissures, a tendency to run concentrically with the rampart. (8) The seas have in general a dark color, like the plains inside the great craters. The color of the plateaus is lighter. A coating of special whiteness covers the central peak in many of the craters. (9) The surface of the Moon is strewn with a large number of white patches. In the majority of cases these patches surround craters of small or moderate dimensions, and if the central opening should appear to be wanting, it may be said, with a probability almost amounting to certainty, that a different illumination will reveal its existence. All the craters in the same region are often surrounded by these white aureoles. Specially to be noted among these objects are the curious streaks which radiate from a small number of craters, and extend to enormous distances. (10) The divergent streaks have no effect on the relief of the regions which they traverse. They cross the plains and the mountains without inflection, and show no tendency to flow down the valleys."

Several interpretations of these facts present themselves as possible. The following are regarded by the authors as the most satisfactory:

"The rills are, as we have already explained,[1] the traces of the imperfect joining of floating masses, having their origin in an early period when a solid crust was forming on the Moon's surface.

"The seas, and likewise the great craters, are the result of successive sinkings due to the action of forces having various origins.

"The polygonal form of the great craters was determined by the preëxistence of the straight rills, which in many cases constituted lines of least resistance and acted as limits to the final sinking of the crust.

"The same cause determined the grouping and alignment of the craters in certain directions. The projecting ramparts and the central mountains indicate that the subsidence was preceded by a general elevation of the region occupied by a crater, and by the formation of a volcanic cone near the summit of the protuberance. The elevated

[1] *C. R.*, 121, 79–85, 1895.

veins which are found on the surface of the seas mark the course of ancient fissures filled by lava which solidified in obtrusion.

"The similar aspect of the seas and the flat interiors of the craters, the isolation or disappearance of the central peaks, indicate the partial invasion of the surface by lava which afterward solidified.

"The aureoles which surround the craters are deposited masses of volcanic cinders which were explosively projected. The divergent streaks resulted from the dispersion of these cinders to great distances under the action of variable atmospheric currents. The size and depth of the lunar craters have been regarded by various authors as irreconcilable with a volcanic hypothesis. There is, however, plenty of room for the belief that each great crater was not, as a whole, an eruptive opening, but that the space occupied by it was the theater of an intense volcanic activity, manifesting itself by a number of more or less large orifices. The testimony in favor of this view which is offered by all the facts relating to the aureoles and streaks seems to us absolutely decisive.

"The seas, more recently formed than the greater part of the craters, correspond to extensive sinkings of a crust already resistant, and capable of sustaining itself over a certain area. Their general arrangement reproduces with considerable fidelity that of the great depressions in the terrestrial crust, and notably that of the inland depressed areas which have been studied by geologists.

"The narrow fissures found to exist on the borders of the seas indicate concentric sinkings. Some of them appear to be rents in the soil caused by eruptive elevations."

Thus the authors have sought to refer all the characteristic and important features of the Moon's surface to a probable cause; and in doing so, they have found the basis for a chronological classification, which is given below.

"Taking as a point of departure the state of complete fluidity, we recognize as a well-marked first period that in which masses of scoria, agglomerated into fields of greater or less extent, appear upon the surface; these fields are often broken, and in cooling are subsequently reunited. The lines of junction and of rupture often remain, disposed according to a regular system which is clearly shown on our photographs.

"The formation of a continuous crust on the Moon marks the beginning of a second period, where the lava which accumulates at

certain points under the influence of the Earth's attraction or any other cause, no longer finds a free vent to the surface, and is obliged to create one. In an envelope still capable of offering moderate resistance, this tendency is revealed by the formation of cracks. The lava flows out by the way thus offered to the surface of the Moon. It soon solidifies, giving to the overflowed portions the aspect of a smooth plain.

"As time passes the crust becomes more solid; it opens only under the action of interior pressures powerful enough to raise it, by which swellings are produced, followed by depressions. This third period is that of the appearance of the great craters.

"At length elevations become exceptional and embrace areas more and more restricted. General sinkings, on the contrary, are still possible, and can extend over areas greater than the crust is capable of upholding without support. We are therefore led to distinguish a fourth period; that of a general sinking giving rise to the depressed areas known as seas.

"The existence of spots and streaks which cover indifferently the seas and the plateaus, the ramparts and the floors of the craters, incontestably proves the existence of a phase of activity more recent than the solidification of the surface of the seas. Hence there is room to consider a fifth period, in which, on account of the constantly increasing thickness of the crust, the most intense volcanic forces can only manifest themselves by temporary, though violent, eruptions, limited to orifices of small dimensions. These phenomena partly change the color of the surface without effacing the relief of its principal features.

"The white streaks issuing from definite centers radiate in all directions, and sometimes extend to enormous distances. Their recent origin is demonstrated by the fact that they leave absolutely intact the relief of the regions which they traverse, and their general appearance and character is evidence in favor of the former existence of a lunar atmosphere which it would seem difficult to confute."

Finally, the authors express the belief that it is not certain that the fifth period has entirely closed and that the era of absolute quiet has set in upon the Moon. The forms we see were probably produced when the thickness of the crust did not exceed ten or twelve kilometers —a thickness which is but a small fraction of the Moon's diameter. In the absence of all precise indications as to the age of these forma-

tions, we are permitted to regard general movements of the surface as still possible, and also such volcanic outbursts as have led to the formation of the great white streaks.

The selenographic theory here outlined resembles in many respects that of Suess, particularly in the important fundamental assumption of forces which are merely such as must have been active on the surface of the Earth, though modified in their action by the conditions peculiar to the Moon. There are, however, some important differences. According to Suess, the seas are "fusion hearths," formed by the remelting of the thin, partly solidified crust, and hence they represent one of the earliest stages in the formation of the surface; while their rocky walls are formed, not by a falling away of the crust on one side at an advanced stage of cooling, but by the pushing outward and crowding together of masses of slag at the rim of a great partially melted area. In the hypothesis of Loewy and Puiseux the formation of the seas is placed in the fourth period; in that of Suess, in what corresponds to their second.

The white rays or streaks have always been one of the chief selenographic puzzles, and every variety of explanation may be found in the great number of articles that have been written about them. The suggestion that they are volcanic ashes formerly ejected from craters has been previously advanced. Regarded in this aspect their most intractable feature is their straightness. Schaeberle supposed that they were straight and narrow for such great distances because there was no atmosphere to cause a deviation from the original plane of projection, but he was obliged to evoke the aid of an unknown extraneous force to account for their unsymmetrical distribution. According to W. H. Pickering, the rays are made up of smaller streaks, each of which proceeds from a minute crater. The component streaks are all tailed the same way, in consequence of atmospheric currents generated by eruption at or near the central crater, and condensation of the liberated vapors in a remote region. Suess regards the rays as due to bleaching of the surface rocks by acid vapors, which once escaped from orifices distributed along the line of original fissures. The late A. C. Ranyard thought they might be due to hoar frost, deposited from aqueous vapor escaping from such fissures as those just mentioned. These are a few examples of the more recent explanations.

If it is true, as some observers assert, that the eye can perceive with a small telescope details which cannot be photographed with a

very much larger one, the photograph must still be superior to eye observation for showing general features, and the relations between objects widely separated on the Moon's surface. If, further, there is any possibility (it would seem to be a small one) that volcanic force may again be called into play, the nature and extent of such changes in the surface as we may expect them to produce could be satisfactorily determined only by reference to photographs like those now being taken at Paris and Mt. Hamilton. But photographic maps of the Moon have been looked forward to so long, and have been discussed so often, that it is unnecessary to point out their various fields of usefulness. K.

Reviews.

Ueber Gesetzmässigkeiten in den Spectren festen Körper. F. Paschen. *Wied. Ann.* **58,** 455–492, 1896.

Under this well-chosen title, Dr. Paschen has not only furnished abundant experimental evidence for thinking that the radiation of energy from heated solids obeys laws, but he has also discussed his observations with consummate skill and has shown us just what some of these laws are.

The statement of the problem which Dr. Paschen has set before himself may, perhaps, be most simply made as follows. The spectrum of a gas, when produced by any of the ordinary electrical means, is said to be described when the wave-length and intensity of each line is given. Considerations of temperature enter, so also those of pressure, but at present the all important factors are the distribution of intensity in the line, and the wave-length (or frequency) of the maximum intensity. This information concerning spark or arc spectra is, in general, obtained partly by the eye, partly by the photographic plate, and partly by the bolometer. When, however, the spectrum of a solid body is under examination, whether it be considered as a limiting gaseous spectrum in which all wave-lengths are represented, or as a gaseous spectrum of one single line widened out so as to cover the whole range of wave-lengths, its description is complete, in either case, only when, for each particular wave-length, we know the intensity of the radiation and the temperature of the source. And, for measurable temperatures, the one available instrument is the bolometer or radiomicrometer.

The accurate experimental determination of this intensity as a function of temperature and wave-length in solid bodies, the accurate description of these results in a single mathematical expression, and the comparison of observations with mathematical predictions may be said to be the threefold object of the work under rewiew. Dr. Paschen's spectro-bolometer, with its fluorite prism, and his skill in the use of this difficult instrument, are too well known to need description in these colums. The solids to be heated were spread in layers

upon sheet-platinum. The platinum was heated by an electric current. The temperature of the source was thus under easy control, and was varied from 117° C. to 1001° C. Temperatures were measured by means of a well calibrated Pt—Pt.Rh. thermo-pile. The experimental part of the work (not to mention the extraordinarily large number of errors which must be either eliminated or allowed for in bolometric work), hinges on the determination of two sets of curves. One of these expresses the intensity as a function of the wave-length, while the temperature of the source remains constant. This is called the "energy curve." The other expresses the intensity as a function of the temperature, while the bolometric strip remains fixed at one wave-length. This is called the "isochromatic curve." For the energy curve, the temperature is the variable parameter; for the isochromatic curve, the wave-length is the variable parameter.

The report of this investigation is so free from the padding which sometimes permits a reviewer to condense results that any fair summary of Dr. Paschen's results calls for a complete translation. Among these results the following are some of the most important:

First.— If the energy curves are plotted, using as coördinates, *not* the intensity, J, and the wave-length λ, but $\log J$ and $\log \lambda$, it is found that these curves are congruent — have the same form — for all temperatures. This congruence, which was predicted by W. Wien, proves to be an exceedingly happy fact; for it enables one not only to fill out the absorption gaps which are introduced into the curve by the carbon dioxide and water vapor in the atmosphere, but also to complete the entire energy curve when once a few points on it have been measured, reminding one of the classical feat which the palæontologist performs with a few bones of an unknown skeleton.

The formulæ which H. F. Weber, W. Michelson, and Köveslighety have proposed as descriptions of the energy curve are disposed of, courteously but decisively, on the ground of incompetence; while Wien's expression for the intensity is practically identical with that at which Paschen arrives by experiment, viz.,

$$J = \frac{c_1}{\lambda a} e^{-\frac{c_2}{\lambda T}}$$

where T denotes the absolute temperature, while c_1, c_2, and a are constants.

Second.—The wave-length of maximum intensity, λ_m in any energy curve, varies inversely as the first power of the absolute temperature for which the curve is plotted. This experimental result is also a mathematical inference from Wien's expression. It is found, however, that the following expression

$$\lambda_m \, T^{0.9500} = 1866.5$$

represents the observations (for iron oxide, at least) still better than the hyperbolic curve.

Third.—So much for the *position* of the maximum intensity, λ_m If now we inquire concerning the *value* of the maximum intensity, J_m as dependent upon the temperature, the experimental result is summarized in the following equation:

$$J_m = C \, T^a$$

$$\text{where} \begin{cases} C = 3.519 \times 10^{16} \\ a = 5.6577 \end{cases}$$

This equation is to be carefully distinguished from the equation of energy curve. For iron oxide, then, the whole story is complete when the mean energy curve and the general values of λ_m and J_m (the two preceding equations) are given.

Fourth.—The *total* radiation is roughly proportional to the fifth power of the temperature. More exactly

$$\int J \, d\lambda = c'' \, T^{4.708}$$

where c'' is not a function of the temperature.

Fifth.—The isochromatic curves are plotted for iron oxide at six different wave-lengths; when logarithmic coördinates are used, these curves also are shown to be congruent. And this proves to be a fact of great utility; for knowing a few points on any isochromatic curve it is possible to complete this curve, and thus to determine the temperature at which the *energy* curve has its maximum at the particular wave-length which serves as a parameter for this isochromatic. Knowing the temperature of the maximum one can then, by the equation given above, viz.,

$$J_m = C \, T^{5.6577}$$

evaluate this intensity without having either to produce or to measure a temperature which may be inconveniently high for present laboratory methods.

If space were of no consideration, it would be interesting to follow a special method of plotting the isochromatic curves by which they are congruent with the energy curves. We must also forego a description of the method by which the radiation of the shutter is allowed for; likewise the manner in which one plots the intensity per unit difference of frequency as a function of the frequency. Dr. Paschen points out that what is true of iron oxide is also true of the other solids which he has examined, the only change in the general equation occurring in the constants. One is at a loss to know which to admire the more, the manipulative skill that furnishes normal spectra in the infra-red with a prism and bolometer, or the masterly discussion which gives such elegant graphical and algebraic expression to the results. In any case, one is forcibly reminded of Professor Karl Pearson's contention that the so-called "exact sciences" have forever disappeared and have been replaced by "descriptive sciences." And physics may be said to be a descriptive science *par excellence*, since it speaks a language which is terse and clear beyond the dreams of any rhetorician. The completion of Dr. Paschen's investigation will be awaited with unusual interest. H. C.

Experimental Determinations of the Temperature in Geissler Tubes. *Phys. Rev.*, **4**, 191–206, and *Wied. Ann.*, **59**, 238–251, 1896.

WHEN the history of the Geissler tube comes to be written, it is not unlikely that the last ten years of this century will stand out as an important period. For within this decade much definite information has been obtained, especially in the laboratories at Cambridge and Berlin, concerning the physical conditions under which electrical discharges occur in these tubes.

The investigation under review is an experimental determination of the local temperatures which prevail, inside the tube, during the passage of a constant current from a storage battery of 1250 volts. Incidentally Mr. Wood describes two neat experimental devices: one for using the Geissler tube as the bulb of an air thermometer, thus measuring the change in "average temperature" which results from the passage of the current; the other a delicate manometric tube for showing the extreme rapidity of the pressure variations (thermal changes) inside the tube when an intermittent current is employed.

The main part of the paper, however, is devoted to the investigation of the two following questions:

First.—At any one point in the tube, how does the temperature vary as a function of the current strength?

Second.—The current remaining constant, how does the temperature vary from point to point, as one passes from anode to cathode?

The first of these questions was answered by sealing a stationary bolometer in the tube and varying the current; while, for the second, Mr. Wood very ingeniously employed a Torricellian vacuum as a Geissler tube. This permitted him to use a movable bolometer arm carried on the upper end of a slender glass rod, running up through the mercury into the vacuum.

The chief results of the work are represented in several well chosen diagrams, which should be consulted by everyone interested. The most important of these results are two in number, viz.:

First.—The rise in temperature at any point in the tube, so far as can be detected by a bolometer wire $\frac{1}{30}^{mm}$ in diameter, is trifling, not exceeding 30° C. when a current of 3 milliamperes is used.

Second.—The distribution of temperature along the tube is that which one would predict if all the heat developed were "Joule heat." This is the assumption of Warburg; and the assumption is justified by Mr. Wood's results.

Taking due account of the more or less rapid changes brought about by conduction and convection, the distribution in this gaseous conductor appears to be exactly that which is met in the case of a solid composite conductor conveying a constant current, viz., the heat is developed most rapidly in those parts in which the fall of potential is most rapid.

In all other sources of intense luminosity we are so accustomed to find high temperatures that one finds it difficult, in the absence of conclusive experimental evidence to the contrary, to believe that there is not, *somewhere*, in the Geissler tube also a source of high temperature. Mr. Wood has taken the precaution to use continuous currents. But to what degree are these currents really "continuous" in a medium which is continually "breaking down" under electrical stress? Is it not possible that here also the "streaks" which Wüllner observed with the rotating mirror may also occur?

On the other hand, it does not appear either impossible or improbable that the supposition of E. Wiedemann may be correct, viz., that

the electromotive forces brought to bear upon the tube may put into rapid vibration the ether associated with the molecules of matter (*Aetherhüllen*) without, at the same time, essentially altering the translational kinetic energy of the molecules. It will be remembered that Professor Michelson has offered independent experimental evidence for thinking that the temperatures of the Geissler tube are low (ASTROPHYSICAL JOURNAL, **2**, 251, 1895).

These questions demand for their answer apparently a finer grade of machinery than that employed by Mr. Wood; albeit his measures are doubtless the best that have ever been made. In using a bolometer wire only $\frac{1}{30}^{mm}$ in diameter the limit of the method has perhaps been nearly reached; for even if the diameter of the wire were of molecular dimensions, and yet large enough to convey a bolometer current, it would seem highly probable that the rapid changes in temperature which might be indicated by it could no longer be followed by any instrument now available.

If, as a matter of fact, the temperatures indicated by Mr. Wood's bolometer strip approach asymptotically those indicated by an indefinitely small wire, and if the current is not in some way the *immediate* cause of light then the conditions of luminosity in the Geissler tube would appear to be, in many ways, analogous to those which Dr. Huggins has suggested for nebulæ. In his presidential address (*Brit. Assoc.* 1891) he says:

"On account of the large extent of the nebulæ, a comparatively small number of luminous molecules or atoms would probably be sufficient to make the nebulæ as bright as they appear to us. On such an assumption the average temperature may be low, but the individual particles, which by their encounter are luminous, must have motions corresponding to a very high temperature, and in this sense be extremely hot.

"In such diffuse masses, from the great mean length of free path, the encounters would be rare but correspondingly violent, and tend to bring about vibrations of comparatively short period, as appears to be the case if we may judge by the great relative brightness of the more refrangible lines of the nebular spectrum.

"Such a view may perhaps reconcile the high temperature which the nebular spectrum undoubtedly suggests with the much lower mean temperature of the gaseous mass, which we should expect at so early a stage of condensation, unless we assume a very enormous mass; or

that the matter coming together had previously considerable motion, or considerable molecular agitation."

It would appear in keeping with the simple physical properties which gases exhibit, in contrast with liquids and solids, that the Geissler tube, so far from maintaining its old position as a veritable *terra incognita*, should shortly become perhaps the best understood of all sources of light. H. C.

THE RADIATIONS OF URANIUM AND ITS SALTS.

Sur diverses propriétés des rayons uraniques. HENRI BECQUEREL *Comptes Rendus*, **122**, pp. 501, 559, 689, 762, 1086; **123**, 855. See also a review by G. Sagnac, *Jour. de Phys.*, 3d series, **5**, 193–202 1896.

IN the above papers is given an account of the properties of certain radiations of uranium, and the various uranium compounds. These radiations were discovered by Henri Becquerel, in the early part of 1896, and are most interesting because they seem to be intermediate between the ordinary ultra-violet radiations of the arc or spark discharge, and the X-rays discovered by Röntgen.

The properties of the uranium radiations are briefly these, as observed by Becquerel:

The radiations are emitted by all known salts of uranium, and best of all by the element itself, even if kept in a dark space for six and more months. The intensity of the radiation, as measured by its photographic action, decreases slightly in this interval. It acts upon both dry and wet photographic plates.

The radiation is hardly perceptibly increased by exposure of the substance to magnesium light, the radiation from a Crookes' tube, or to daylight, but an intense illumination may increase the radiation slightly. Crystals of uranium nitrate which have been formed in darkness have the same radiating power as crystals exposed to light.

The radiations pass through most bodies more easily than do the X-rays. This is specially true of the metals. Lead, however, is quite opaque, and tin, fairly so. Water and most solutions, even metallic, are transparent.

The radiations are not homogeneous, as is shown by the fact that the absorption by a superposition of screens of copper and aluminium

or of platinum and aluminium is less than the sum of the absorptions produced by each separately.

The radiation can be reflected and refracted, as is proved by direct reflection from a steel mirror or from a concave mirror of tin, and by refraction through a crown glass prism. Total reflection can also be observed. The effects, however, are so irregular that no measurements of the index of refraction can be made.

The radiation can also be polarized, as appears from the fact that two superimposed crossed tourmalines are much more opaque than two whose axis are parallel.

The radiation discharges bodies which are electrically charged if it falls upon them. This is proved by means of an electroscope. If the radiation passes through a gas (*e. g.*, air or Co_2), the gas will itself discharge the charged electroscope if it be blown against it, even if there is no direct action of the uranium on the instrument.

Care was taken in all the experiments to guard against the action of any uranium vapors, and the effects are found to depend largely on the amount of uranium present, quite independently of the elements with which it may be in composition.

As noted above, these uranium radiations have properties in common with both light and X-rays; and this fact serves to strengthen the belief that X-rays are transverse ether-waves of extraordinary shortness.

J. S. AMES.

JOHNS HOPKINS UNIVERSITY,
December 1896.

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1. *Anomalous Dispersion Curves of some Solid Dyes.* A. PFLÜGER. *Wied. Ann.*, **56**, 412–432, 1895.
2. *On the Indices of Refraction of Solid Fuchsin.* B. WALTER. *Wied. Ann.*, pp. 394–396, 1896.
3. *On the Anomalous Dispersion of Absorbing Substances.* A. PFLÜGER. *Wied. Ann.*, **58**, 670–672, 1896.
4. *On the Indices of Refraction of Metals at Different Temperatures.* A. PFLÜGER. *Wied. Ann.*, **58**, 493–499, 1896.

DISPERSION curves of some of the strongly absorbent dyes had been given by Pulfrich, Ketteler and others, using alcoholic solutions, and E. Wiedemann, Lundquist and Merkel had given similar curves

for solid dyes obtained from measurements of elliptic polarization; the difficulty of interpreting the former results, and discrepancies among the latter, together with possible uncertainties in their theoretical deduction, led Pflüger to make the observations given in this first paper. He used solid prisms of very small angle (40″ to 140″) and a method substantially that which Kundt used in his work on the indices of refraction of the metals. Wernicke had previously used solid prisms of fuchsin, but of such large dimensions that no observations could be made inside the absorption bands. By using prisms of the very small angle above given Pflüger is able to observe the dispersion curve continuously from $\lambda = 6710$ to $\lambda = 4100$, though the image of his slit inside the strongly absorbent bands is, as would be expected, by no means sharp. That the great variation in the absorption from the thin to the thick side of his prism did not introduce any noticeable systematic error in his results seems to follow, as in Kundt's case, from the fact that he used prisms of varying angle, and found no systematic variation of the indices with the angle.

The substances examined were: fuchsin, cyanin, Hoffman's violet, magdaleroth, malachitegrün; and the most interesting results are: (1) inside the absorption bands the index of refraction decreases with decreasing wave-lengths; (2) fuchsin and Hoffman's violet gave values of the index less than unity, at the short wave-length end of their absorption bands; (3) inside the absorption bands the index varies with the angle of incidence (or, Snell's law does not hold).

The article of Walter gives a tabular comparison of indices of refraction of solid fuchsin for certain strongly absorbed wave-lengths, calculated on the one hand, from indirect observations before mentioned, by E. Wiedemann, Glan and others, and Walter, with those given by Pflüger in the preceding article. Walter calculated his values by means of Cauchy's theory from his observations of elliptic polarization, and there is a very close agreement between them and those of Pflüger, and very wide discrepancies between these and the others. In Pflüger's second paper he makes a similar comparison between his results and Walter's for "diamantgrün;" the agreement is again quite good inside the absorption bands, and poor outside. Walter's values for the weakly absorbed wave-lengths were obtained from total-reflection measurements, and why they should in both cases differ so widely from Pflüger's is not clear. Pflüger also calls attention to the values of indices less than and equal to unity, above mentioned; these and

similar results of Kundt's for some metals are of interest in connection with the view that the Röntgen rays are transverse ether vibrations of very short period for which all substances examined have indices equal to unity.

The fact that a number of the metals arrange themselves with respect to their indices of refraction in the same order as with respect to their electrical and thermal conductivities, led Kundt to an investigation of the temperature variation of these indices, to see if the same similarity held there. He found that the temperature coefficients of the indices were of about the same absolute magnitude but of opposite signs to the temperature coefficients of the conductivities. His results were not verified by later observers, notably Drude and Zeeman; Pflüger has therefore repeated Kundt's observations with greater care and he finds no measurable temperature variation of the indices of Ni, Au, and Fe. C. E. MENDENHALL.

On a New Photographic Method of Photometry and its Use in the Ultra-Violet. H. TH. SIMON. *Wied. Ann.*, **59**, 91–115, 1896.

THE photometric method of Simon may be briefly outlined as follows: Two portions of a photographic plate are simultaneously exposed in exactly similar ways to light from two sources — the one the standard source, the other the light to be compared. The latter is then gradually weakened, and the plate at the same time uniformly moved so as to expose a new portion of its surface. Upon development that part of the plate exposed to the standard source will be uniformly darkened throughout its whole whole length, while the other portion will gradually diminish in density. At a certain point of the length the two halves will be of equal density; by knowing the extent to which the strong light has been weakened at this instant, its value in terms of the standard is directly obtainable. Of course this method is only applicable to the comparison of homogeneous lights of the same wavelength. The apparatus as devised and used by Simon consists of the following parts: (1) a spectrometer, having a quartz train, and in place of the eyepiece, a second slit and a device for moving the photographic plate past this slit. (2) The light-weakening apparatus, for which purpose the ordinary sectored disk is used, but so arranged that the apertures of the disk (of which there are three, of 60° each) can be gradually closed by a second disk — and this while the two disks are

rapidly rotating. (3) Connecting mechanism by means of which any given angular opening of the apertures of the disk is made to correspond to a definite position of the sensitive plate. The plates so exposed and developed have a dark line separating the two halves which are to be compared, and in order to avoid the difficulties of comparison which this introduces a special comparison device is used. This consists of an objective, bi-prism, and eyepiece, and has its objective end covered with a diaphragm containing two semi-circular apertures; it is so adjusted that one of the images, formed by the bi-prism, of aperture *a* is brought accurately opposite and in contact with an image of *b*. The two halves of the developed plate being placed in front of *a* and *b*, respectively, and moved along, the position of equal density can be found to within about $0^{mm}.6$. It is seen that this method assumes that the photographic action is the same for a given light time of exposure, whether that exposure is continuous or intermittent; previous observers have differed on this point—and it is probably not true at the limit of sensibility of a plate; but Simon seems to have justified the assumption for the conditions under which he worked, by comparing disks having the same total aperture, but having individual apertures of greatly different sizes. Under ordinary conditions the method is accurate to about 0.5 or 0.6 per cent. The method is also applicable to the measurement of absorption coefficients, and has been applied with quite satisfactory results to one case, which is given in the original paper, together with full details of adjustment.

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